

NASA CONTRACTOR REPORT 177953

NASA-CR-177953
19850027077

MINIATURE INFRA-RED DATA ACQUISITION AND TELEMETRY SYSTEM

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**CONTRACT NAS1-17944
SEPTEMBER 1985**

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Space Administration

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NF01024

PREFACE

This final report describes work performed at the Research and Development Laboratories of Energy Optics, Inc. for the National Aeronautics and Space Administration Langley Research Center from December 20, 1984 to June 14, 1985 in fulfillment of NASA contract #NAS1-17944, Miniature Infra Red Data Acquisition and Telemetry System.

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PROJECT SUMMARY

The Miniature Infrared Data Acquisition and Telemetry (MIRDAT) Phase I Study was performed to determine the technical and commercial feasibility of producing a miniaturized electro-optical telemetry system. This system would acquire and transmit experimental data from scale models in a variety of different types of wind tunnels. The following design aspects were deemed important because of the severe environment encountered in wind tunnel testing:

- o low power consumption
- o miniature size
- o ability to operate in various energy fields
- o ability to perform accurately over extended temperatures.

During the Phase I study, miniature prototype MIRDAT telemetry devices were constructed, successfully tested in the laboratory and delivered to the user for wind tunnel testing. A search was conducted for commercially available components and advanced hybrid techniques to further miniaturize the system during Phase II development. Although no telemetry systems which meet all of the user requirements are commercially available, experimental results indicate that hybrid construction techniques could produce a MIRDAT system capable of meeting those requirements. A design specification was generated from laboratory testing, user requirements and discussions with component manufacturers. Finally, a preliminary design of the proposed MIRDAT system was committed to paper for Phase II development.

The MIRDAT telemetry transmitters having a volume of only one cubic inch would have far-ranging applications, and could be beneficially applied to the fields of medicine and biomedicine, aerospace, physical security, oil field data acquisition, process control, and remote sensing.

Section 1.0

PHASE I OBJECTIVES AND QUESTIONS ADDRESSED

Currently there are no commercially available telemetry systems featuring low power consumption, miniature size, and multiple transmission media. The major objectives of the Miniature Infrared Data Acquisition and Telemetry (MIRDAT) Phase I Study were:

- o Determine the feasibility of designing and constructing a miniature electro-optical telemetry system for operation in scale models in wind tunnel testing.
- o Determine the commercial availability of components capable of operation in the wind tunnel environment.
- o Construct prototype models of the system and perform laboratory tests.
- o Create and document a preliminary design specification for Phase II development.

To achieve the above objectives, important questions raised in the Phase I proposal about the feasibility of designing and constructing a MIRDAT unit were addressed. The questions, listed below, helped to identify important areas for further study.

What environmental specifications must be addressed?

The wind tunnel environment would present diverse environmental conditions to the MIRDAT system. The system may be required to operate over the full mil spec (-55 to +125 degrees C) temperature range. The system must perform in magnetic fields exceeding 5000 gauss, and in electrically noisy environments consisting of 20 kHz switching transients at loads

exceeding 1 kW. Laser light and RF fields also typify the MIRDAT environment. The MIRDAT system would be required to operate in such an environment for test sessions lasting from a few minutes to more than half an hour.

What quantity and types of transducers must be connected?

Typical experiments involve the use of strain gauge balance type transducers. These devices produce millivolt output levels with excursions above and below zero volts, and require a differential analog front end for amplification. In addition, some tests require the use of pressure transducers to measure atmospheric pressures on the surface of the model under test. A telemetry system with 16 input channels (or eight differential input channels) should prove sufficient for most testing.

What data rate and data throughput are required?

Sample rates are typically 1 to 50 samples per second per channel. An important requirement is for the system to perform near simultaneous data gathering from all channels. Erroneous data may result if samples are taken from the channels in a skewed fashion, whereby the samples are significantly offset from one another in time. Extremely fast sampling rates could overcome this problem (i.e. sample rates at orders of magnitude greater than the frequency response of the metal structure being tested). As an alternative, a sample and hold device could be incorporated into the system to acquire data from all channels simultaneously, but a significant price would be paid

in system volume.

A study of the frequency response characteristics of objects the size, shape and volume of small wind tunnel models was undertaken as a part of the MIRDAT program. An analysis of several sizes and shapes of models was performed in order to determine their natural resonant frequencies. Figure 22 depicts the analysis and formulae used in the computation. The approximate natural resonant frequency was found to be about 2 Khz or an order of magnitude greater than the maximum proposed sample rate. The result of this finding is that if the model being tested experiences high frequency vibrations from dynamic rather than static testing, simultaneous sample and hold devices will be a necessity. Figure 20 depicts the mathematical analysis undertaken.

Is a two-way, full duplex data link useful?

The capability to transmit data and commands in both directions between the telemetry transmitter and the remote telemetry receiver could prove to be useful in some applications. This capability could be used to activate and deactivate the data acquisition system, and ultimately be used to remotely program data acquisition variables such as sample rate and amplifier gain.

What volumetric and weight limitations must be considered?

Data acquisition methods currently used in wind tunnel experiments impose physical limitations on the model under test. Conventional telemetry systems utilizing hardwire data links may produce incorrect test results because of wire-

induced turbulence and strain.

Wireless telemetry modules eliminate problems associated with hardwire techniques, but the modules must be extremely small to fit within test models. Since small size is not normally a consideration in the design of telemetry systems, a major objective of the MIRDAT study was to study the physical aspects of the proposed system to determine the limits of miniaturization.

Models tested in magnetic suspension wind tunnels (typically the smallest type) are less than 16 centimeters in length and less than 2.5 centimeters in diameter. A telemetry system used in such models would be required to occupy a volume of only 2.2 centimeters in diameter by 3.8 centimeters in length. Additionally, the system must fit within the cylindrical shape of a model's fuselage. This shape was found to be extremely inefficient in terms of printed circuit board space utilization.

A successful MIRDAT system would achieve small size by employing advanced hybridization for miniaturizing the required electronics. A number of construction techniques were investigated in order to make the best possible use of available space. Different materials were investigated in order to determine the one most suitable for construction of a hybrid substrate.

What hardware interface techniques are necessary?

The MIRDAT device requires a large number of connections for data input. Most electrical connectors, including

those commonly used in micro-miniature aerospace applications, were found to be too large for the MIRDAT system (typically 1.25 centimeters in length for the male/female pair). No commercially available connector has been found which is short enough to fit within the confines of the smallest models. An interconnection technique sometimes used in printed circuit boards (when extremely low profile IC socketting is required) was chosen as the best possible compromise. This technique utilizes a hollow female pin which is pressed into the printed circuit board until it is nearly flush with the top surface. A corresponding male pin is soldered to the interconnecting wire and attached to the female pin.

Likewise, there is no room in a small model for an "on-off" switch for the telemetry system. The MIRDAT device incorporates an automatic power sequencing circuit activated by remote control which conserves the system battery during periods of inactivity.

What beam width and transmit range tradeoffs can be made?

The telemetry system is required to transmit data over short ranges, between one to five meters, within the wind tunnels. With typical wind tunnel diameters of 15 centimeters or less, narrow beam angles may be used between the MIRDAT device and its receiver. Various infra-red transponders of the type manufactured by Energy Optics can be used in larger wind tunnels and in models requiring wider beam angles and increased transmission distances. Figure 1 depicts beam angles utilized in the MIRDAT device and outlines calculations for required emission power and receiver sensitivity.

What cost constraints are practical?

A secondary objective of the MIRDAT project was the design of a system with both commercial and experimental value. As such, the device must be affordable in comparison to competitive data acquisition devices. The device should also be designed for use in various wind tunnel types and numerous types of models. Cost for hybrid MIRDAT units may range from a few hundred to a few thousand dollars, not including amortized engineering costs. Accurate cost figures will depend upon the final design and the total quantity to be manufactured. Unit cost for a MIRDAT hybrid telemetry transmitter based on parts specified in the Phase II preliminary design is estimated at \$700.00 each at a production quantity of 100 units (amortized Phase II engineering costs not included). Cost at a production quantity of only five units is projected to be \$2,200.00 to \$2,500.00 per unit.

Section 2.0

WORK PERFORMED

The MIRDAT system is designed to provide a here-to-fore unavailable capability for extracting stress and pressure data from small aircraft models by wireless means. The system, which relies on two-way pulsed IR telemetry for remote data monitoring in wind tunnel testing, includes three microcomputer based subsystems. A miniature device mounted inside the model under test for data acquisition and transmission is called a Telemetry Transmitter Unit (TTU). A second device located outside the wind tunnel for TTU interrogation and data reception is called the Telemetry Receiver Unit (TRU). A peripheral subsystem, the Remote Control Data Terminal (RCDT), allows an operator to control the test and observe the received test data in realtime.

The MIRDAT Phase I Study afforded an opportunity to determine the feasibility of producing miniature data acquisition and telemetry units incorporating pulsed infra-red (IR) transmission. To organize the study, a feasibility test plan was developed and followed (section 2.1), and an investigation into commercially available components for the system was performed. Two types of MIRDAT prototype TTUs were constructed and tested in the laboratory.

The initial TTU prototype was a small wire-wrap device for use in firmware development and limited testing. The second configuration was a miniature MIRDAT TTU capable of operating in a scale model for limited testing by the end user. Figure 15 is a schematic of the Phase I miniature prototype. This miniature

model was invaluable for demonstrating the feasibility of the MIRDAT concept, providing a testbed for communications protocols and TRU software, and as a tool for investigating various construction techniques. The miniature MIRDAT prototype was constructed for lab testing and subsequent delivery to the user on completion of the Phase I effort. In addition, system specifications and a preliminary design for the proposed MIRDAT system were documented.

2.1 Development of Feasibility Test Plan

At the onset of the program, a meeting was held with cognizant NASA personnel in order to gain a comprehensive understanding of design goals and system requirements. A major objective of the meeting was to gather information for preparation of a preliminary design specification. This specification was delivered to NASA in the form of a system block diagram which outlined two possible approaches for the MIRDAT prototype (see Figure 2 and 3).

In addition, a general software specification was prepared to help the user expedite software interface development and testing (see Figure 4). A set of preliminary requirements was developed and integrated into the MIRDAT feasibility investigation as a result of the meeting.

To insure an orderly and timely approach to the problem, the following feasibility test plan was outlined:

FEASIBILITY TEST PLAN

- I. Problem Definition
 - A. Meet with user
 - B. Hold staff discussions for ideas
- II. Definition of Overall System Specifications
 - A. Hardware
 - B. Software
- III. Design and Construction of Prototype Hardware
 - A. Create and document design
 - B. Deliver preliminary design to user
 - C. Order components
 - D. Construct breadboard prototype
 - E. Debug and test prototype in laboratory
 - F. Construct miniaturized version for delivery
- IV. Specification of Prototype Software
 - A. Define communications protocol
 - B. Define protocol between Telemetry Receiver Unit (TRU) and RS232 interface
 - C. Deliver preliminary specifications to user
- V. Laboratory Testing of Prototype Software
 - A. Define types of prototype tests to be performed
 - B. Define on-site tests to be performed by user
- VI. Integration of Test Results Into Specifications
- VII. Investigation of Available Components
- IX. Document Design of Commercial Version
 - A. Utilize refined specifications to generate new design
 - B. Perform check of selected components against operating requirements

X. Definition of Phase II Technical Objectives

- A. Prepare list of anticipated problems in hybrid development
- B. Prepare Phase II preliminary test plan
- C. Prepare preliminary specifications for user review
- D. Investigate similar data acquisition systems

XI. Preparation of Phase I Final Report

XII. Preparation of Phase II proposal

2.2 Component Selection and Search

A major portion of the time spent on MIRDAT Phase I involved the selection and subsequent availability search for suitable miniaturized components. Most if not all of the components in a hybrid circuit are either surface mounted or utilize a die on board technique. Not all devices, however, are commercially available in die or surface mounted form. Some microprocessor types, specifically those with onboard (ultra-violet) erasable memories (EPROM devices), are generally not available in miniaturized form. CMOS integrated circuits, because of their special handling and testing procedures, are also not widely available.

Part of the Phase I study involved selection of a suitable analog to digital (A/D) converter, associated front end circuitry, and signal amplifying and multiplexing devices. Care was required in the selection of these devices to insure final design performance within speed, accuracy, and power constraints.

2.3 Prototype Construction

As specified in the Phase I MIRDAT proposal, prototype units were constructed which were modeled after non-miniaturized telemetry systems previously developed at Energy Optics, Inc. These units were built to verify miniature electro-optical telemetry system designs and to demonstrate the feasibility of the concept.

While not meeting ultimate user requirements for size, power consumption, speed of operation or accuracy, the miniature prototypes were sufficiently small to fit within the confines of user scale models, thereby providing a testbed for experimentation. They were also utilized for development and testing of communications protocol firmware to be used in the modified production TRU device, previously developed for Energy Optics' commercial products. Existing protocols required modifications to provide for a low power mode of operation in the MIRDAT device.

Laboratory test results were used as a basis for the documented preliminary production design. Experiments were performed both in the laboratory and in the user's wind tunnels to verify operation of the device in high electrical and optical noise environments. Descriptions of experimental setup procedures and results are included in section 3.4.

2.4 Electro-Optics and Communications

The prototype MIRDAT system employs free-space electro-optical communication technology to transmit digital data in both directions between a telemetry transmission unit (TTU) and telemetry receiver unit (TRU). The system includes an IR

transceiver which is mounted to the interior portion of the wind tunnel for data reception. An IR transponder, an integral part of the TTU, faces the transceiver from the rear of the model under test. Both devices use a Gallium Arsenide (GaAs) light emitting diodes (LED) as a source of pulsed radiation in the near IR spectrum (900 nanometers).

2.4.1 Transmitter (Emitter)

The transmitted radiation is non-coherent but spectrally narrow, with a bandwidth of 50 nanometers. The LEDs are operated in pulsed mode in order to achieve a hundredfold increase in peak power output over CW transmission methods (refer to section 4.0). This technique also provides a simple method for direct digital encoding of the data. Transmitted pulse width is nominally 1.0 microsecond.

2.4.2 Receivers and Amplifiers

The receivers used in each device employ silicon photodiodes operated in the photoconductive mode. Incident radiation is optically filtered to limit interference from ambient light sources. The photodiodes are AC coupled to high gain voltage amplifiers with cutoff frequencies designed to pass the lowest order component of the transmitted pulse train.

2.4.3 Frequency Response and Bandwidth

Frequency response of the receiver amplifier and passband of the optical filters were selected to achieve the maximum signal to noise ratio at a reasonable cost. The receivers were designed to reject continuous light sources and to pass only a narrow band of light wavelengths centered around the 900

nanometer region. Electronic filtering attenuates both low and very high frequency AC signals. The combination of optical and electronic filtering eliminates interference from pulsed lasers and fluorescent lights.

2.5 EMI/RFI Shielding

Electrically the device is shielded from sources of external RF radiation. The shielding also prevents the MIRDAT from interfering with nearby instruments, due to oscillations of the internal logic and microprocessor. An LC filtering technique is used between the MIRDAT power source and electronics and at the signal input. A Faraday shield, made of Mu metal, acts as a protective outer layer. High frequency transient noise from external sources is absorbed by Ferrite beads selected to suppress frequencies above the response of the model under test.

2.6 Laboratory and Environmental Testing

MIRDAT prototype devices were subjected to a series of laboratory tests to verify proper operation. A TRU and CRT terminal were configured to establish communications in the testbed.

2.6.1 Range Tests

The electro-optics were configured to communicate over distances likely to be encountered in wind tunnel tests. Specific tests included:

- o Measurement of optical power densities at distance of 4.57 meters
- o Determination of required receiver sensitivity at 4.57 meters
- o Measurement of transmit beam angles in mock-up tunnel
- o Transmission and terminal display of simulated data.
- o Temperature testing from 0° to 55°C.

Test descriptions and results are presented in section 3.4.

2.6.2 Environmental Tests

Only limited environmental testing was performed on the Phase I prototype devices. No effort was made to construct devices capable of operating at required accuracies over extremes of temperature and humidity. Rather, the study focused on investigating the availability of components for the Phase II design which could be made to operate in harsh environments. The resulting component list was later used to produce a preliminary design for a commercial version of the MIRDAT device.

Section 3.0

RESULTS OBTAINED

User interaction provided valuable insight into the varied problems of acquiring data from extremely small scale models in wind tunnel experiments. The MIRDAT Phase I study attempted to solve as many of these problems as possible, while retaining practical solutions to the design of a miniaturized data acquisition and telemetry unit. The most desirable MIRDAT TTU would, of course, require exceedingly small amounts of physical space and electrical power. Such a telemetry unit would find wide acceptance in several industries as a data acquisition and transmitting device.

3.1 Hardware Development

A major accomplishment of the MIRDAT Phase I study was the construction of miniature prototype telemetry devices without the benefit of an in-house hybridization capability. These devices were valuable for demonstrating feasibility and verifying the electro-optical telemetry system design. Figure 21 depicts the different construction techniques considered. Once constructed, the TTUs were utilized for experiments involving EMI/RFI interference, communications protocol, and transmission range. In several instances the prototypes provided insight into the ultimate design requirements for the MIRDAT system. Although no hardware delivery was called for or specified in the Phase I contract, the miniature TTU prototype developed was delivered to the user for further testing at the conclusion of the Phase I contract. This prototype, although not as small as a production version, serves to prove the feasibility of the

MIRDAT concept.

The MIRDAT telemetry transmitter device requires support equipment to capture the electro-optical telemetry data and to transfer it to a host computer or controlling terminal. This peripheral equipment consists of an electro-optical transceiver which is an integral part of the Telemetry Receiver Unit (TRU). The transceiver attaches to the side of the wind tunnel and communicates with the TTU. The TRU relays the received data to a host computer (RCDT) in RS232 format. See Figure 5 (pictorial of MIRDAT unit) and Figure 6 (transponder mounting location).

A device previously developed at Energy Optics for reception of IR telemetry data was adapted for use in the MIRDAT program. The device is termed a transceiver to describe its ability to both transmit and receive data electro-optically. A schematic of the transceiver is shown in Figure 16. Physical appearance of the device resembles a pair of binoculars, where one tube contains the transmitting element while the other contains the receiver. The transmitting LED radiates one microsecond pulses of 0.175 watt peak optical power into a 3.0 degree, full angle beam width. The receiving device is much more sensitive than necessary for this application, having a four degree field-of-view and a field strength sensitivity of 48 nW/cm^2 (48×10^{-9} watts/centimeter squared).

The transceiver is attached to the TRU via a cable which passes both data and power. The transceiver attaches to the inner wall of the wind tunnel with its optics oriented toward

the rear of the test vehicle containing the TTU and its associated transponder. An alternate technique employs a prism type device to bend the infrared beams, allowing the transceiver to mount outside the tunnel with only a small portion of the optics protruding into the tunnel. Figure 6 graphically depicts both mounting techniques.

A portable data acquisition device previously developed at Energy Optics for commercial use was modified to serve as the MIRDAT TRU prototype. The TRU schematic is shown in Figure 17. The TRU consists of a single-board microcomputer with 16,384 bytes of random access memory; 8,192 bytes of program storage memory; and interfaces for RS232 and electro-optical communications. The TRU was originally developed to serve as a portable battery-powered data acquisition unit in a remote meter reading system. It contains a small, precision digital cassette recorder for mass data storage. For the MIRDAT application, the TRU was re-packaged by replacing the battery pack with an AC power supply, and the digital cassette recorder was not used.

Existing communications firmware had to be re-written for the specialized MIRDAT communications protocol. The TRU can be interconnected to either a mainframe, small personal computer, or CRT terminal for control and display of acquired data. Figure 7 lists the commands recognized by the TRU when connected to a terminal or computer. The TRU interprets commands received through its RS232 port and acts on those commands by interrogating the TTU at selected intervals. After each interrogation sequence, data collected from the TTU is passed

to the controlling device. Since the TTU is designed for low power consumption, the initial communications protocol causes it to switch from a low power quiescent state to an active state. When active, the MIRDAT gathers a set of data and transmits them electro-optically to the TRU. The TRU can be used with any future commercial versions of the MIRDAT system with only minor (software or packaging) changes required. Existing user-owned personal computers could also be used for reception and processing of data acquired by the MIRDAT device if they contain an integral RS232 port.

3.2 Range Calculations

The maximum communications range of the MIRDAT system is a function of many variables relating to the IR transmitter design, receiver design, available power, and ambient interference. Atmospheric attenuation is not considered in this application due to the limited distances and controlled nature of the experiments. In the uniform beam model seen in Figure 8, maximum communications range is a simple function of transmitter power "P" (watts) and receiver sensitivity "Ps" (watts/centimeter squared). These values are accurately measured in the laboratory by using a calibrated radiometer. Although the output of an IR LED is essentially Gaussian, good results are achieved by assuming that the LED radiation is evenly distributed over the beam's cross section. At a range R, the radiation power density "Pd" is then:

$$P_d = P / (\pi (R \tan \theta / 2)^2)$$

where (θ) is the full angle beam divergence. In a typical example, the power density radiated by the TRU at 4.5 meters (15 feet) is:

$$Pd = .175 / (\pi (457 \tan (3^\circ/2))^2)$$

or

$$Pd = .175 / 3.14 (457 \text{ cm } (\tan 1.5^\circ))^2)$$

$$Pd = 389 \text{ microvolts/cm}^2.$$

The maximum communication distance can be calculated by finding the range at which the transmitter power density equals the receiver sensitivity (P_s):

$$P_s = P / (\pi (R \tan (\theta/2))^2).$$

Solving this equation for R provides a useful range equation:

$$R = \sqrt{(P/P_s * \pi (\tan (\theta/2))^2)}.$$

The maximum communication range from the TRU to the TTU can be calculated by inserting the peak TRU transmit power (.175 watts), the TTU receiver sensitivity ($100 \times 10^{-6} \text{ W/cm}^2$), and the transmit beam width (3 degrees):

$$R = \sqrt{(.175 \text{ W} / (100 \text{ uw } \pi (\tan (1.5^\circ))^2)}$$

$$R = 901 \text{ cm or } 29.5 \text{ feet.}$$

Since the MIRDAT system utilizes two-way communications, the maximum range must be calculated in both directions and the system range will be limited by the weakest link. The maximum range from the TTU transponder to the TRU transceiver is a function of the peak TTU transmit power (0.0059 watts), the TRU transponder receiver sensitivity (W/cm^2), and the transmit

beam width (10 degrees):

$$R = \sqrt{P / (P_s * \pi (\tan (\theta/2))^2)}$$

$$R = \sqrt{(.0059 / (48 \times 10^{-9} * \pi (\tan (5^\circ))^2)}$$

$$R = 2260 \text{ cm or } 74 \text{ feet.}$$

Based on the weaker TRU to TTU link, the maximum communications range for the MIRDAT system electro-optical data link is approximately 880 centimeters or 29 feet.

3.3 Experimental Results

The following section summarizes experiments performed in Phase I. In general, the experiments provided information about prototype operation in the wind tunnel environment.

MAGNETIC FIELD EXPERIMENT

Purpose: Verification of MIRDAT prototype operation in high level DC magnetic fields.

Setup

A wire wrap prototype of the Phase I MIRDAT device was constructed and mounted in a brass enclosure (RF shield). The TTU and a version of the TRU with a hand-held transceiver were shipped to the user for testing in a magnetic suspension wind tunnel. Inputs to the MIRDAT device were configured to produce simulated data. The MIRDAT device was activated and remotely read both before and during operation in the magnetic field. Figure 9 is a picture of the MIRDAT prototype units.

Results

Error-free data was transmitted electro-optically from the MIRDAT device in both normal and magnetic operating environments. A continuous DC field in excess of 800 gauss was applied to the MIRDAT device in order to suspend it magnetically within the tunnel. The device functioned normally and transmitted data was verified to be the same value with or without the magnetic field.

Conclusion

The experiment was considered a success and the MIRDAT unit was found to be operable in high strength DC magnetic fields.

OPTICAL NOISE AND BIT ERROR RATE EXPERIMENT

Purpose: Verification of communications protocol susceptibility to undetected data errors.

Setup

A TRU transceiver and TTU transponder were placed on an optical bench at an arbitrary separation of distance of 90 centimeters. Neutral density filters were placed in the optical paths to simulate long distance by attenuating the transmitted signals. Finally, a rotating disc with variable transmissivity was placed in the optical path to provide periodic signal degradation. Known data was transmitted and continuously verified in both directions. Undetected bit errors were then counted, as were the total number of bits transmitted. An undetected error is defined as an error which is not detected as a function of either the parity or checksum functions.

Results

More than 10^8 bits were transmitted during the experiment, with only 2 undetected errors occurring. The actual number of transmitted bits was 5.76×10^8 , yielding a bit error rate of 3.4×10^{-9} .

RECEIVER SENSITIVITY EXPERIMENT

Purpose: Performance testing of the TRU and TTU receivers to measure sensitivity for the anticipated wind tunnel experiments.

Setup

Part 1, TTU Receiver

The TTU receiver was placed on an optical bench at a distance of 90 centimeters from a test transmitter. The transmitter was operating at a 4 kHz pulse rate. A calibrated radiometer was placed in the same field of view as the receiver. The output intensity of the test emitter was reduced while the TTU receiver was observed for its ability to detect the continuous pulse train. The TTU receiver was operated at yaw angles between +7 and -7 degrees to simulate wind tunnel conditions. Using a calibrated radiometer, observations revealed that the receiver functioned properly at optical power levels as low as 100 microwatts/cm². This level may be considered a minimally acceptable signal level.

Part 2, TRU Receiver

A similar test was conducted with the TRU receiver in place of the TTU receiver. The TTU transmitter was excited and results were measured with the TRU receiver. The TRU receiver operated satisfactorily at power levels of 48 nanowatts/cm².

Conclusion

The TTU receiver must have a field strength sensitivity of at least 218 microwatts/cm² in order to insure reliable communications. This is the available optical power density at a transmission distance of 457 centimeters, with the TRU

transmitter operating at a 4° angle beam divergence. Since the measured sensitivity was found to be 100 microwatts/cm², the receiver is adequate.

A measurement of the available optical power density from the TTU diode at a beam divergence of 6 degrees yields 798 nanowatts/cm² at a distance of 457 centimeters. The TRU receiver must have a sensitivity of 798 nanowatts/cm². Since the TRU receiver had a measured sensitivity of 48 nanowatts/cm², sensitivity is more than adequate for the MIRDAT application.

OPTICAL POWER DENSITY EXPERIMENT

Purpose: Measurement of available optical power densities.

Setup and Results

Part 1, TTU Transponder

The TTU transponder was placed on an optical bench at a distance of 457 centimeters from a calibrated radiometer. The TTU transponder emitter was operated at a rate of 5000 pulses per second, while readings were simultaneously taken from the radiometer. The TRU transponder was swept through an arc of 12 degrees. Measurements taken from the radiometer were used in a range computation equation. Results were plotted (see Figure 18) and are depicted numerically below:

Attitude (degrees)	Measured Value	Converted to uw/cm ²
-6.0	90	.177
-5.5	150	.296
-5.0	200	.395
-4.5	250	.493
-4.0	300	.592
-3.5	400	.790
-3.0	450	.888
-2.5	520	1.02
-2.0	550	1.08
-1.5	580	1.14
-1.0	580	1.14
-0.5	580	1.14
On Axis	600	1.18
+0.5	560	1.10
+1.0	540	1.06
+1.5	540	1.06
+2.0	540	1.06
+2.5	540	1.06
+3.0	540	1.06
+3.5	540	1.06
+4.0	540	1.06
+4.5	520	1.02
+5.0	480	.948
+5.5	440	.860
+6.0	380	.750

$$W/cm^2 = \frac{\text{Radiometer output (mV * Neutral Density Factor)}}{\text{Radiometer Calibration Constant}}$$

$$\text{or } \frac{1.18 * 16}{8,100,000} \quad \text{or } 2.33^{-06} W/cm^2 \text{ or } 233 \text{ microwatts/cm}^2$$

Part 2, TRU Transmitter

An identical test was performed on the TRU transceiver. TRU output power density plot is found in Figure 19. Results for this test are as follows:

Attitude (degrees)	Measured Value	Converted to uw/cm ²
-2.5	.200	98.7
-2.0	.280	138.2
-1.5	.480	237.0
-1.0	.680	335.1
-0.5	.800	395.0
On Axis	.840	414.8
+0.5	.720	355.5
+1.0	.440	217.2
+1.5	.240	118.5
+2.0	.160	79.0
+2.5	.120	59.2
+3.0	.090	44.4

$$W/cm^2 = \frac{\text{Radiometer output (V * Neutral Density Factor)}}{\text{Radiometer Calibration Constant}}$$

$$\text{or } W/cm^2 = \frac{.84 \times 4000}{8,100,000} \quad \text{or } .415 \text{ mw/cm}^2$$

Conclusion

The TRU receiver, must have a sensitivity of at least 798 nanowatts/cm² to insure satisfactory communications. The TTU receiver, which in turn communicates with the TRU transmitter, must have a sensitivity of 218 microwatts/cm² to insure satisfactory communications.

Section 4.0

Electro-Optical Communication Methods and Theory

A variety of methods exist for effecting communications using electro-optics. These methods usually involve imposing the information to be transmitted upon some form of light beam. The beam is modulated in a manner that allows the information to be decoded by a receiving device.

Some of the more typical methods employed are CW modes such as amplitude modulation (AM), frequency modulation (FM), frequency shift keying (FSK), pulse code modulation (PCM), and pulse modes such as direct digital transmission. Each of these methods exhibit advantages and disadvantages as noted below:

<u>METHOD</u>	<u>ADVANTAGES</u>	<u>DISADVANTAGES</u>
AM	Easy to implement	Poor range, high power consumption, noisy
FM	Wide bandwidth	Complex to implement, noisy
FSK	Easy to implement, works well with PLLs, noise immune	High power consumption, short range
PCM	Implemented digitally	Complex timing, high power
Pulse Mode	Low power, long range, noise-immune	Extremely complex timing (requires microprocessor)

From the standpoint of power consumption versus range, no communication method other than direct digital pulse mode lends itself to an application such as MIRDAT. Briefly stated, in the direct digital pulse mode of data transmission, both ends of the link must be in precise synchronization with one another. Digital 1s are represented by the transmission of an IR pulse, and digital 0s are represented by the properly timed

absence of an IR pulse in the serial bit stream. When the transmitter initiates a communications sequence, a synchronization pulse is first transmitted for the purpose of establishing proper timing. The receiving device then waits for a precise interval of time before interrogating its receiver. With this method of communication, the presence or absence of digital 1 bits latched by the receiver bears a direct correspondence to the data bits sent by the transmitting device. Figure 10 depicts a representative transmitted bit stream, showing the synchronization or start pulses and the receive listening periods (windows).

Software (in the controlling microprocessors on both ends of the link) controls timing of the transmitted pulses and detection windows. Several parity bits are transmitted and subsequently tested by the receiving microprocessor. Data is transmitted in groups of bytes called blocks. These blocks may range from 16 to 1024 bytes in length. At the end of each block a checksum byte (the summation of all previously transmitted data) is sent.

The receiving computer calculates its own version of the checksum and compares it to the value received. Errors in transmission, either in the form of parity errors or checksum errors, cause the last data block to be re-transmitted. A continuous exchange (handshake) takes place between the two computers during data communications. Bits are transmitted to acknowledge the successful completion of data blocks and data bytes. Figure 11 illustrates the interchange which takes place during the transfer of a 2-byte block of data. The MIRDAT

communications protocol is divided into initialization and data transfer phases. Each phase is discussed below.

The TRU initiates communications activity by sending a burst of sync bits to the MIRDAT unit. These sync bits or pulses increment a hardware pulse integrator, which applies full power to the unit upon reaching a pre-determined count. The MIRDAT unit uses the precise timing of the pulses (5 kHz or an interpulse period of 200 microseconds) to verify interrogation by the TRU. The unit counts properly timed infra-red pulses until a total of six have been received, and then transmits an acknowledge doublet (spaced at 100 microseconds) 100 microseconds after the sixth sync bit is received. The TRU looks for the acknowledge doublet after each sync bit is sent.

If the TRU sees the first acknowledge bit at the correct time, it waits another 100 microseconds and then looks for the second bit rather than transmitting another sync pulse. If the two acknowledge bits are received, the TRU switches to receive mode and waits for the data to be transmitted by the MIRDAT unit. The TRU returns to transmitting sync bits if the second acknowledge bit is not received and/or properly timed, and continues to perform this sequence until stopped by the console operator.

The MIRDAT unit initiates a data transfer phase after obtaining required data from the data collection devices. The received data is first processed through a Single Error Correction Double Error Detection (SECDED) algorithm (discussed later in this report). Each data byte is transmitted as a 13-bit byte consisting of a start bit (always 1), followed by the 8

data bits of the byte, followed by four parity bits.

The TRU firmware generates a precisely timed window when it expects to receive a bit. If a pulse is received during the window the MIRDAT interprets it as a 1 bit. The initial window is infinitely long to capture the start bit. Detection of the start bit triggers timing for the remaining 12 bits, therefore, the timing is re-synchronized with each start bit to virtually eliminate timing errors. Since both the TRU and MIRDAT units know the exact amount of data to be transferred in each communications sequence, no headers or trailing bytes are required. The transmission period is thus minimized.

An error detection and correction scheme, closely following the design of R.W. Hamming of Bell Telephone Laboratories, was chosen to insure data validity and reliability. In this scheme four parity bits are generated for each data byte, so that a comparison of checked and received data parity bits generates a pointer (syndrome) to the bit which is in error. Complementing this bit and re-checking the parity will provide a corrected data byte if the syndrome is zero. On-the-fly correction is impossible, however, if the syndrome does not reduce to zero after complementing the designated bit, since more than one bit is in error. It is entirely possible that the parity bit itself is the error bit, but this has no effect whatsoever on the validity of this procedure.

Section 5.0

ESTIMATE OF TECHNICAL FEASIBILITY

Based on the findings of this Phase I feasibility study, a miniature data acquisition and telemetry system utilizing electro-optical data transmission is possible to produce using hybrid construction techniques. A careful system design will result in a device which is useful in a variety of applications. Figure 12 depicts Phase II design specifications and goals. Figures 13 and 14 depict the suggested Phase II amplifier frontend and system block diagram.

5.1 Anticipated Benefits

In addition to the obvious benefits the MIRDAT system would bring to wind tunnel testing, a commercial version of the system would be applicable to many areas. Although well-established commercial systems are currently available, no miniaturized systems exist. Potential uses for miniaturized data acquisition and telemetry equipment, such as diagnostic monitoring of automobiles, aircraft, and robots, offer an opportunity for MIRDAT application.

5.2 Technical Limitations

The Phase II MIRDAT design represents the integration of many different design constraints. In such a highly complex system the physical constraints interrelate. Each design variable has an effect on the others, such as available size versus battery capacity versus operating time. The following sections address design parameters (in order of decreasing importance) that became a part of the Phase II design.

5.2.1 Physical

The device's maximum size is a constraint that cannot be compromised. In order for the MIRDAT TTU to be useful in new applications as well as in diverse wind tunnel applications, overall size of the device had to remain within the design goals specified by the end user. A size of less than 2.5 centimeters in diameter and 5 centimeters in length (including connectors, power source, optics, and protective housing) is required.

In addition, the method used for interconnecting cables and changing batteries must be simple, direct, and reliable in order to minimize setup time for experiments. The device must be physically protected both from rough handling and from external sources of electrical, magnetic, and optical noise. The basic physical layout of the device should lend itself well to placement within a heated cavity so that slightly larger models can be tested in cryogenic tunnels in the future.

5.2.2 System Accuracy

A number of factors determine accuracy of the MIRDAT system. Of primary concern is the fact that such a small device has no room for trimming components on the analog portion of the circuitry. All system error parameters such as DC offset, linearity, and gain errors must be corrected by the computer which eventually receives the telemetry data. A calibration program and procedure must be developed to enable this computer to account for error terms.

Selection of system components is also important. Circuitry used for data input scaling or analog to digital conversion must

achieve the accuracy desired by the customer ($\pm 1/4\%$ full scale). This accuracy must further be maintained over the full operational temperature range of the device, which for Phase II versions is specified as -55 degrees C to 125 degrees C.

Speed of data sampling and conversion is also critical to system accuracy. Data sample rates for each channel should be variable from less than 1 per second to 50 per second to insure measurement of rapid transient responses from the model under test. Since a number of data channels may be used for a test, it is desirable to take samples from each channel simultaneously, or nearly so. Data skewing results when samples are taken from sensors placed in different locations on the model. Data skewing is generally prevented when sampling rates are at least twice the maximum frequency response of the material used in the model under test. Although the samples are not truly received simultaneously, the faster sampling rate prevents skewed results. The prototype MIRDAT device can sample at a rate of only 100 microseconds between channels. This results in a maximum skew of only 700 microseconds between channels 1 and 8.

5.2.3 Power

A major concern is the total power consumed by the MIRDAT device in relation to its total overall size, operating time, operating speed, and transmission distance. The Phase II device will utilize a CMOS microprocessor to consume far less power than the NMOS prototype. Batteries for the Phase II device can be the flat button type of lithium, rechargeable lithium, or nickel-cadmium. The operating time must be maintained at 30 minutes

minimum and the transmission distance at 4.5 to 6.0 meters. A CMOS analog to digital converter has been specified to further lower power consumption while providing reasonable (50 to 100 microsecond) conversion speeds.

A power budget (analysis) of the proposed Phase II device was performed. Based on both typical and worst-case estimates, the following results were obtained:

	QUIESCENT	ACTIVE
Analog Front End (8 channel)	.001 A	.035 A
A/D Converter	.001 A	.010 A
Microprocessor	--	.015 A
Power Control Circuit	.005 A	.005 A
Transponder	.010 A	.075 A
	-----	-----
	.017 A	.140 A

The .140 A figure represents a worst case, since the microprocessor, A/D converter, and transponder cannot all be active at the same instant. Also the active state occurs only during data acquisition and transmission. Actual worst case average consumption will likely be closer to .1 A. The system will be active 100% of the time only at the highest possible data acquisition rate. At low data acquisition rates, the duty cycle may drop as low as 10%. A battery capacity of at least 0.1 ampere hours should be utilized to insure operation during extended tests (30 minutes or more).

5.2.4 Noise

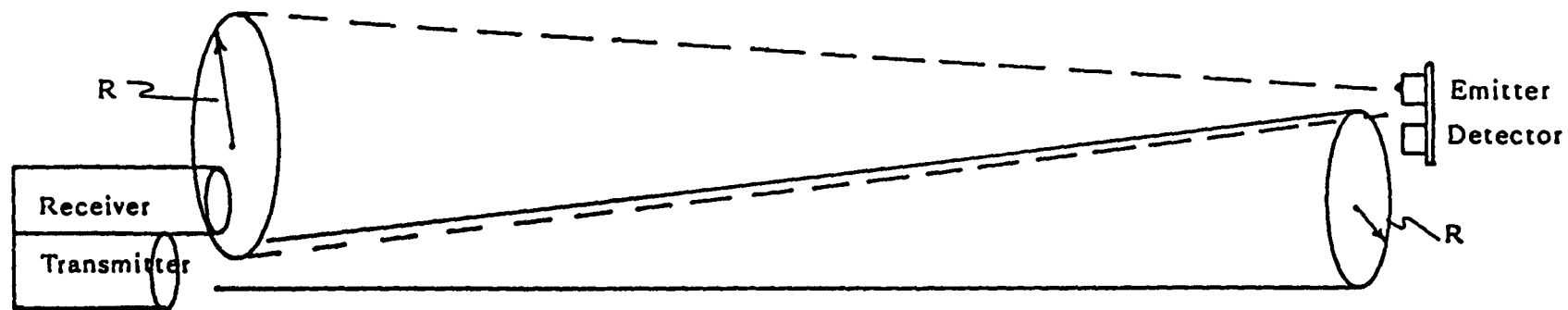
The MIRDAT Phase II design incorporates both mechanical and electrical means to prevent errors or improper operation caused by sources of electrical, optical, or magnetic (EMI) noise. The device is housed in a small metal canister or cylinder which

shields it from magnetic fields. A screened port provides a pathway of entry and exit for the optical signals. The interconnecting data cables pass through ferrite beads selected to attenuate any high frequency noise components of the signal.

5.2.5 System Design Constraints

Thick film hybrid construction techniques are required to achieve the MIRDAT system design goals set forth in this report. Components which have been subjected to full military testing are required for the device to operate in the widely varying temperature extremes encountered in wind tunnel tests. Low temperature (cryogenic) operation is feasible in larger versions of the device which would contain heater elements for the internal electronics. In addition, differing coefficients of expansion would be encountered at low temperatures among the different metals used to construct the device. Considerable design effort must be expended to insure mechanical integrity at low temperature extremes.

Low temperature operation, however, is not without benefits. Electro-optical data transmission generally benefits from low temperatures. Also, the self-heating effects in the emitting device would be greatly reduced or eliminated. Optical (shot) noise in the receiver would be reduced in low temperatures. In general, transmitters of lower power and receivers of reduced sensitivity could be used at low temperatures to achieve the same transmission distances.



37

15'

Computation of Receive Sensitivity: $\leftarrow P_d = \frac{P_t}{\pi (d \tan \theta/2)^2}$ \leftarrow Computation of Emitted Power:

Computation of Emitted Power: $\longrightarrow P_t = P_d \pi (d \tan \theta/2)^2 \longrightarrow$ Computation of Receive Sensitivity:

TRANSMIT/RECEIVE BEAM PATTERNS

Fig. 1

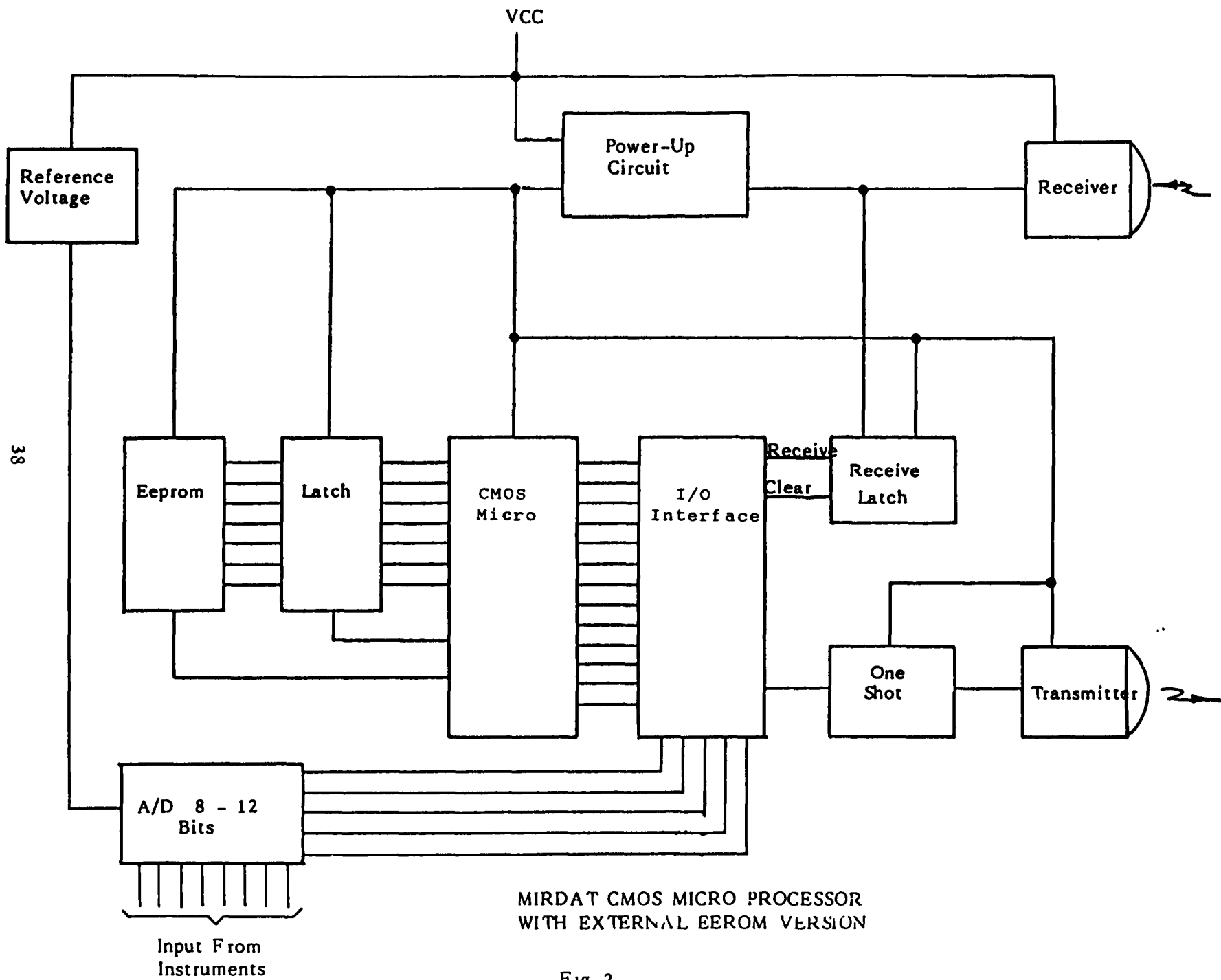


Fig. 2

Fig. 3

PHASE I SOFTWARE SPECIFICATION

The MIRDAT system is scheduled for delivery to NASA in prototype form in early June 1985. Our goal is to deliver a prototype piece of hardware which demonstrates our ability to construct a data acquisition system using micro miniaturization. We plan to make use of existing software and communications protocol in order to complete the project in a timely and cost effective manner. Accordingly, the MIRDAT prototype shall function as follows:

1. The existing EOI IRMADAC data communications protocol (2 way) shall be used.
2. Attached to the start of each communications attempt will be a 5khz "wake-up" header similar to that utilized in the AA-MCUI device.
3. No attempt will be made to massage or manipulate any of the analog data. Upon interrogation by the TRU all data shall be transmitted four times electro-optically to the Telemetry Receiver Unit (TRU).
4. The TRU shall consist of an AA version MCU (less tape drive) with outboard (bread boarded) RS232 level compatible drivers. The TRU shall perform an error detection and correction on the 16 analog values at the completion of the data transmission.
5. Each interrogation by the TRU will end with transmission of an RS232 data packet to a host computer or terminal.
6. The MIRDAT system will revert to a low power mode of operation after a data transmission (successful or otherwise).
7. The MIRDAT system (when doing data acquisition) shall attempt to acquire data from all channels at the fastest possible rate in order to minimize the skew time between sets of data samples.

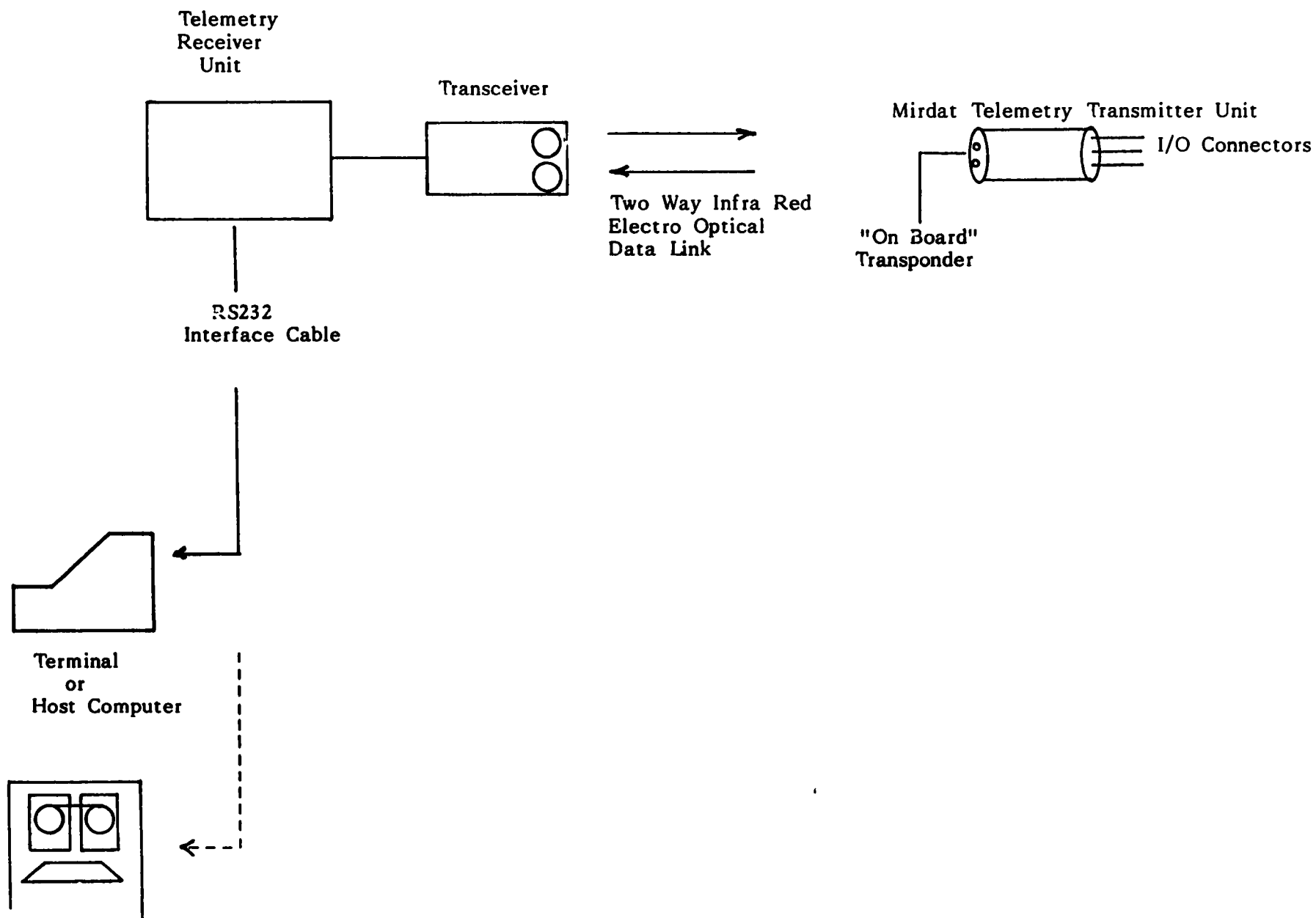
8. The actual A/D converter to be used will be specified at a later date.
9. The processor to be used in the MIRDAT system shall be either an 803S or NSC800.
10. A prototype MIRDAT and TRU should be available for software testing by 3/18/85.
11. RS232 data packets shall be formatted as follows: (ASCII)

SOM	Ch # NN	SP	VVVV	CR	LF	Ch # NN + 1	VVV	CR	LF	EOM
-----	------------	----	------	----	----	----------------	-----	----	----	-----

12. The TRU shall respond to the following commands from:

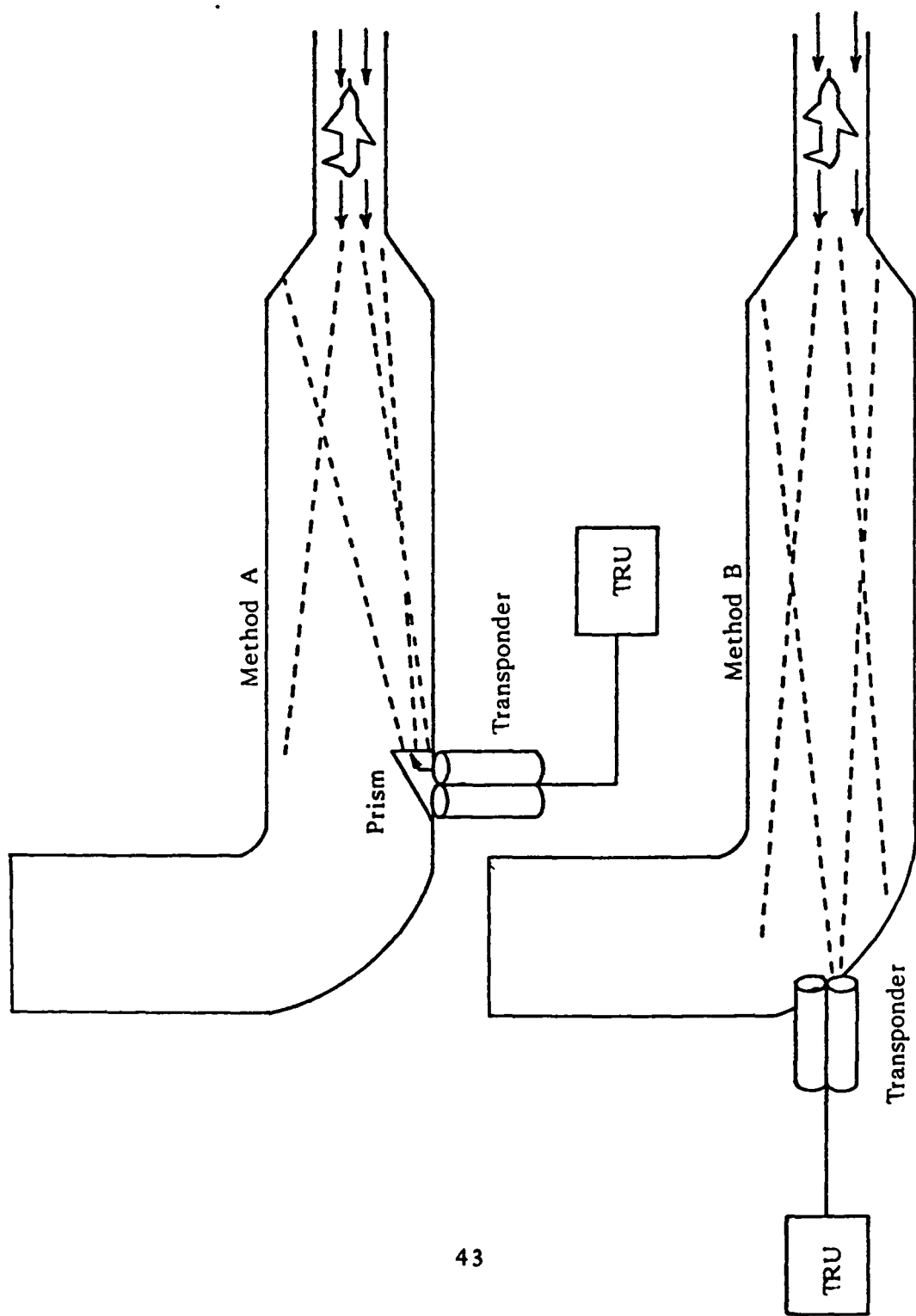
S_{TX}	O	N	N	N	CR	= Acquisition Rate in Milliseconds
S_{TX}	1	X	X	X	CR	= Start Test
S_{TX}	2	X	X	X	CR	= Terminate Test

STX = Control "C"



MIRDAT CONCEPTUAL BLOCK DEAGRAM

Fig. 5



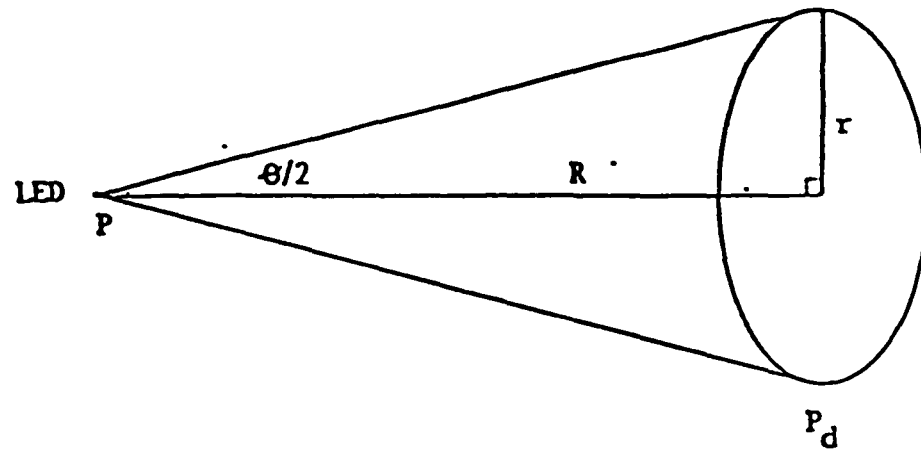
Transponder Mounting Locations

Fig. 6

<u>COMMAND</u>	<u>ACTION</u>
^C 0 NNN <CR>	Set sample period where N = no. of 100 millisecond periods between samples. Default = 10 per second
^C1 <CR>	Begin test and sample mirdat unit at intervals as specified above.
^C2 <CR>	Terminate test
"DEL"	Interrupt test if communications have been suspended ^C1<CR> will restart.

TELEMETRY RECEIVER UNIT COMMAND SUMMARY

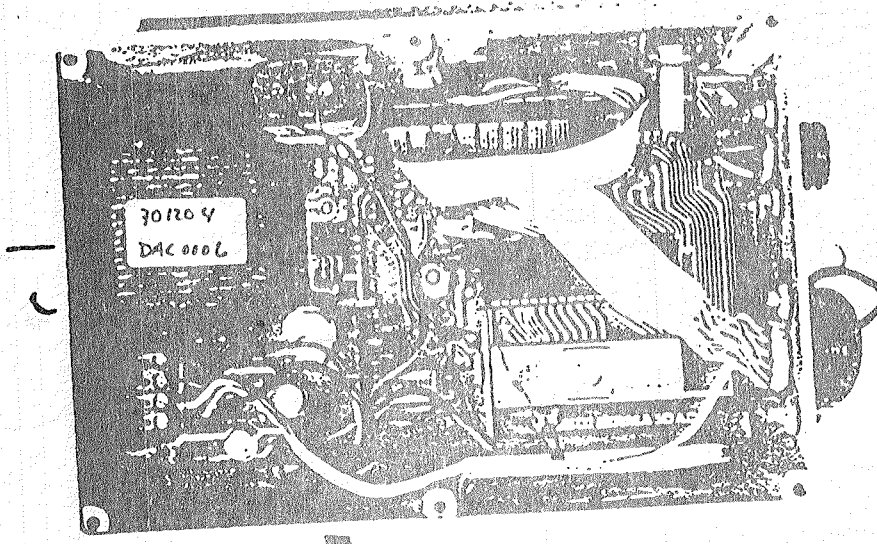
Fig. 7



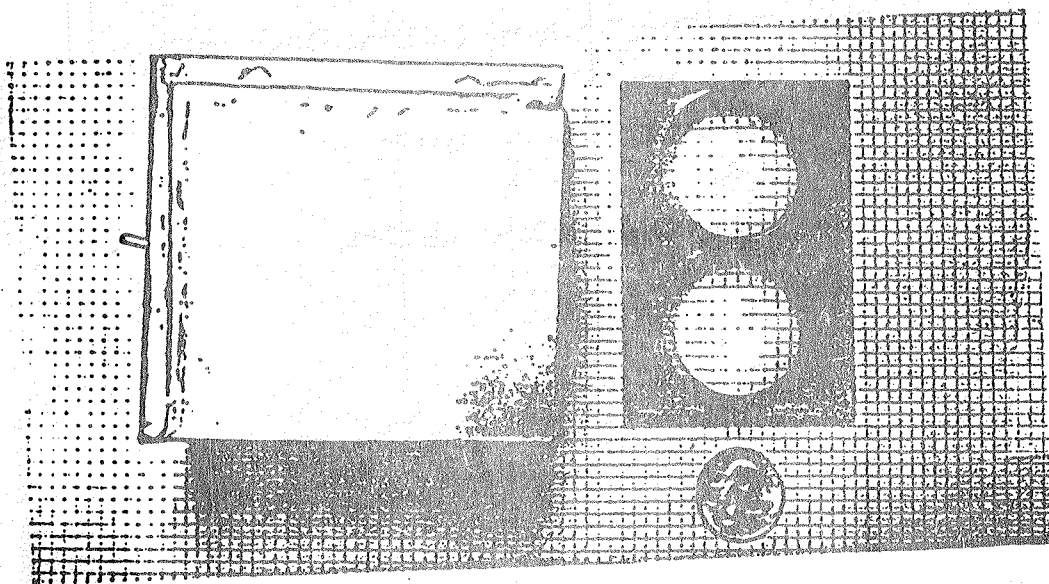
- P = Peak Transmit Power (radiant flux) watts
- P_d = Power Density (irradiance) watts/cm²
- θ = Full Angle Beam Divergence
- R = Range
- r = Radius of Beam Cross Section

UNIFORM BEAM MODEL

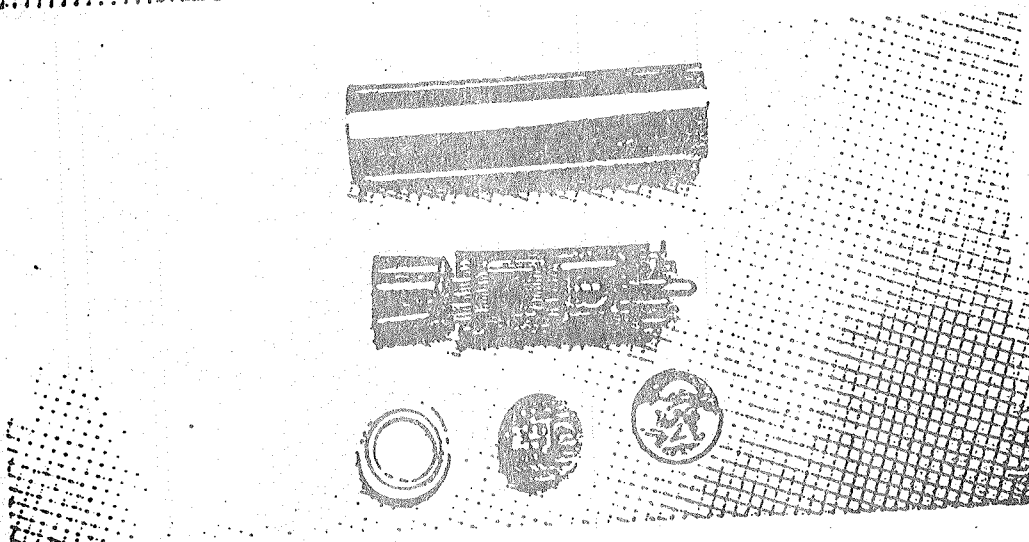
Fig. 8



Original Data
Acquisition System



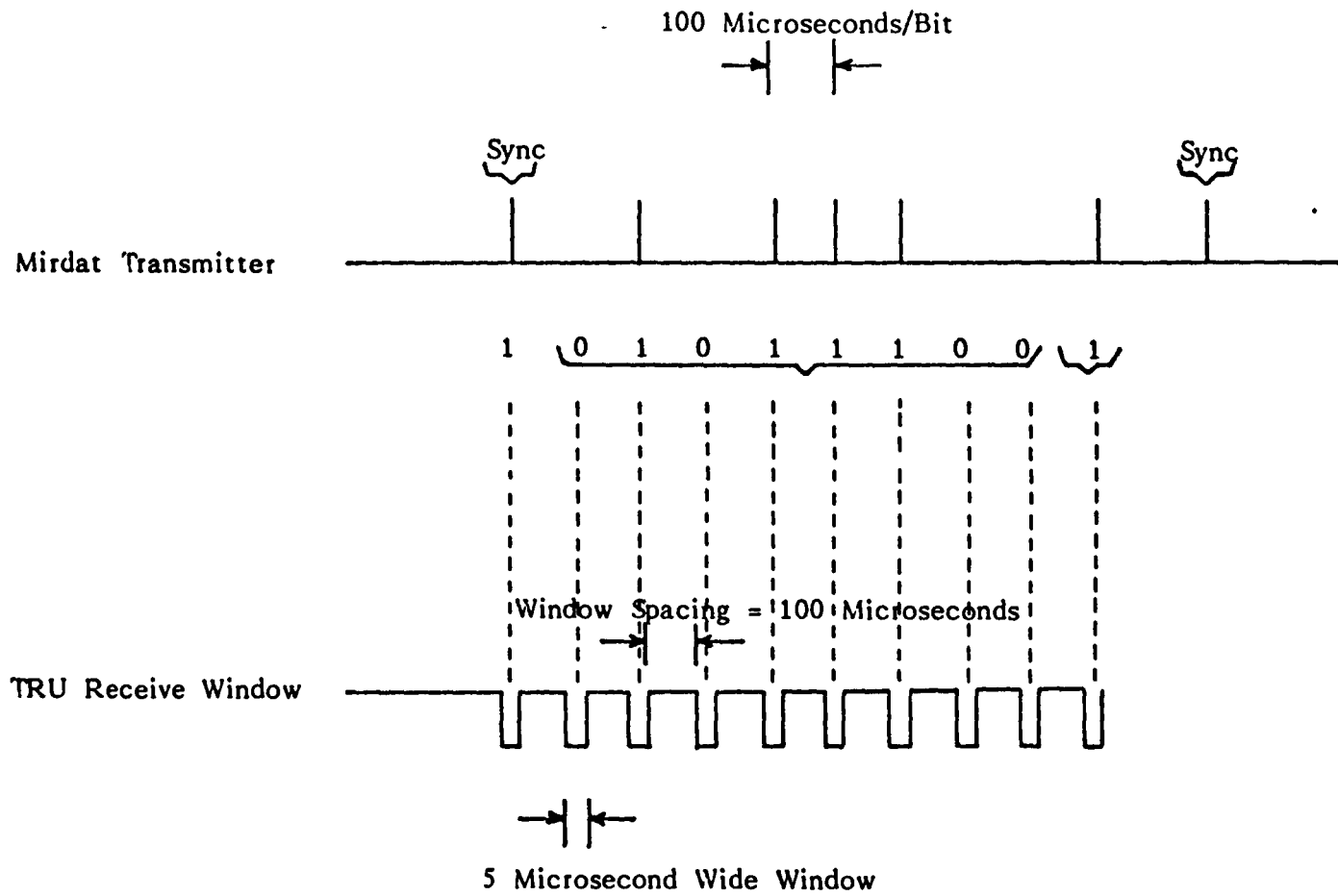
Mirdat
Phase I Wire
Wrap Proto-
type



Miniature
Mirdat Unit
With Electro
Optical
Transponder

MIRDAT PROTOTYPE PICTURES

Fig. 9



Transmitted Bit Stream

Fig. 10

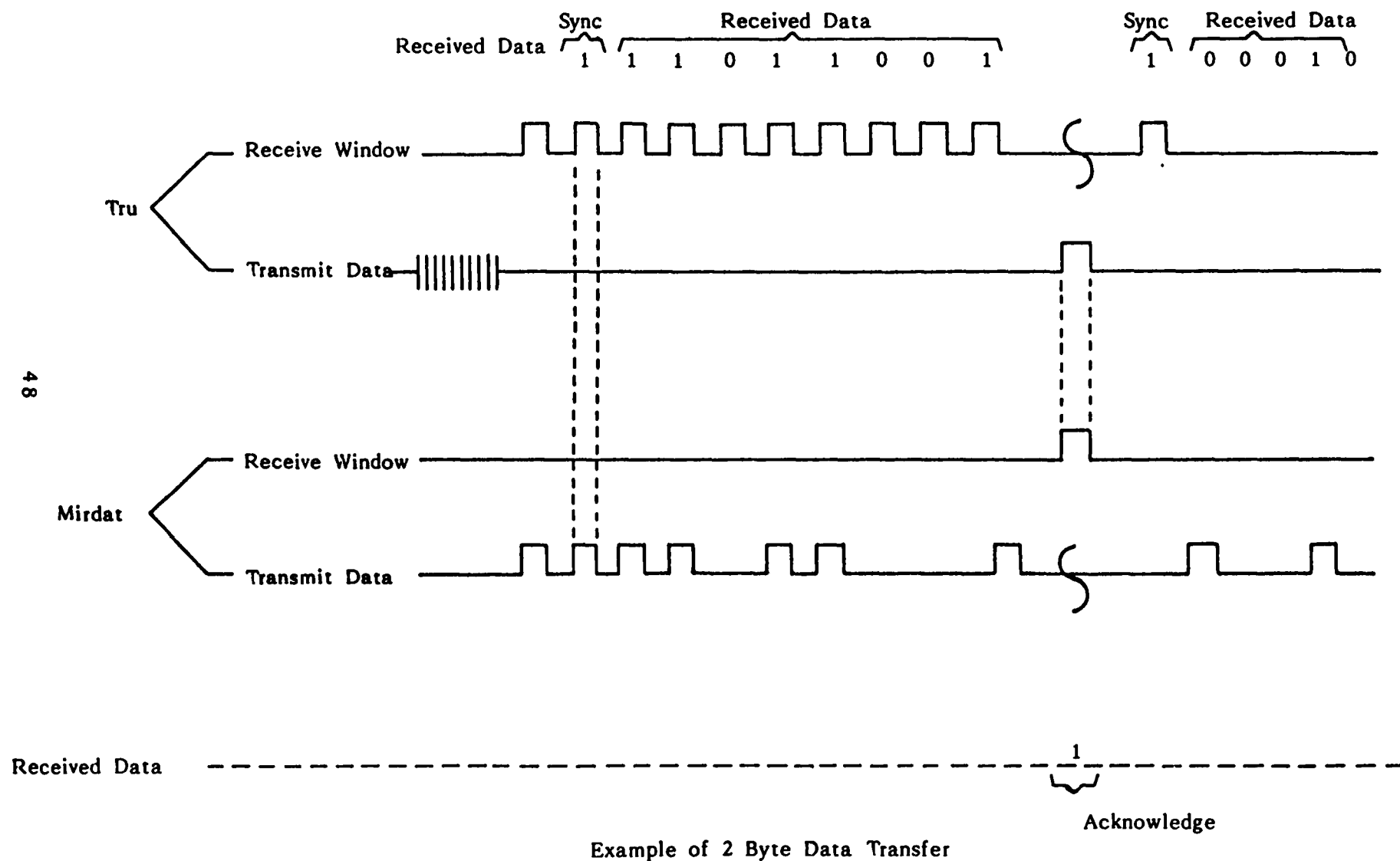


Fig. 11

SPECIFICATIONS FOR PHASE II MIRDAT

Physical

Diameter: 2.2 cm or less
Length: 1.8 cm or less
Weight: 2.5 oz
Container: Mu metal canister
Transmission range: 4.5 meters
Transmission rate: 20,000 bps
Environmental range: -55 to +125 degrees C

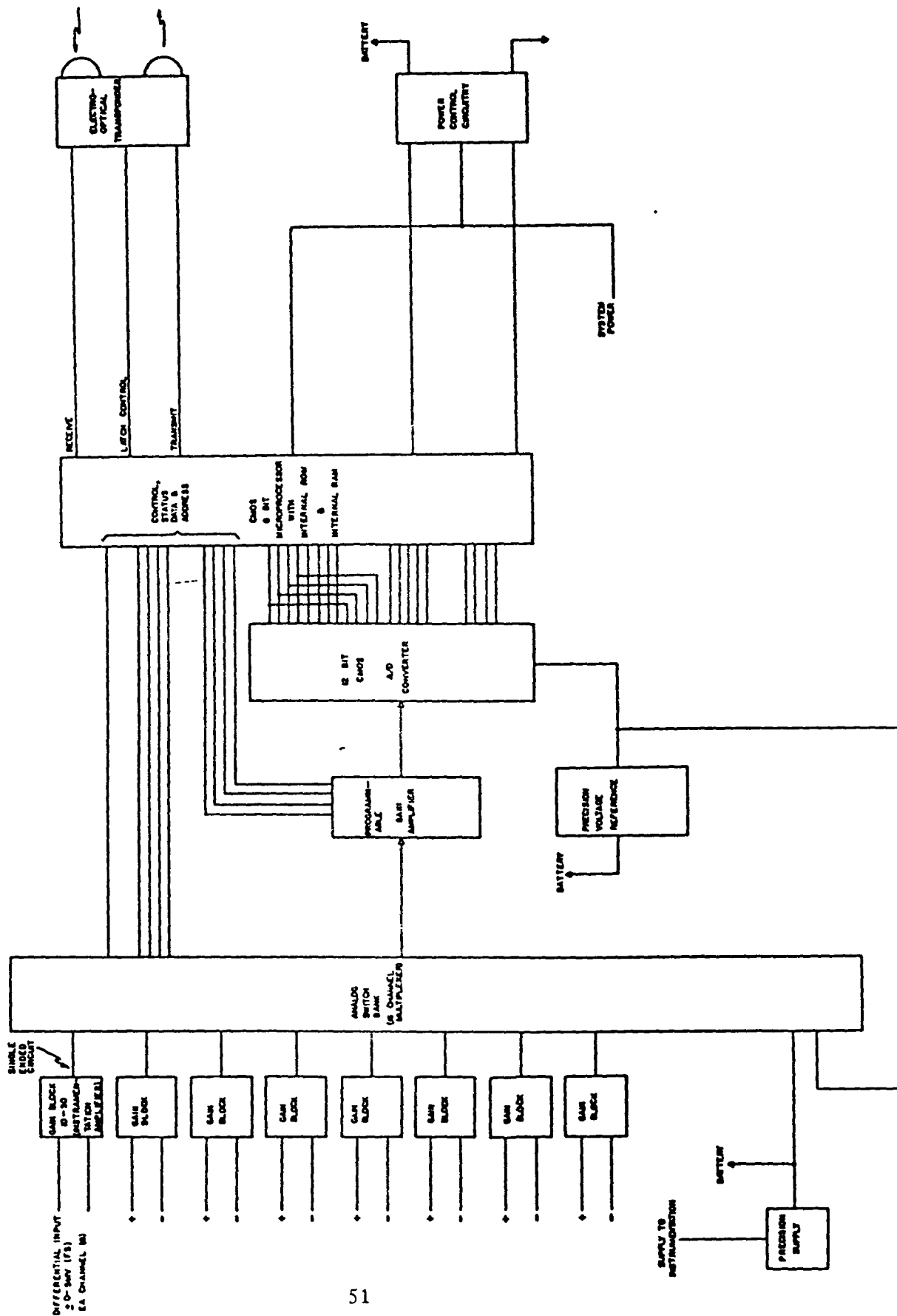
Electrical

Power source: Internal batteries (replaceable)
Operating time: 30 minutes, +1.5 hours quiescent
Power consumption: Operating (transmit) 100 mA
 Quiescent 10 mA or less

Data Acquisition System

No. of channels: 8, with differential inputs
Sample rate: Variable from 1 per 5 seconds to
 50 per second
A/D converter: 12 bit
Front end: Instrumentation amplifiers +/- 5 mV
 full scale, with sample and hold on
 each channel.
Overall system accuracy: +/- 1/4% FS over operating
 temperature range*

* To achieve this accuracy, all error such as drift, offset, linearity, and others will require compensation in and by the receiving computer. Size limitations prevent the use of trimming devices within the MIRDAT unit itself.



MIRDAT PHASE II BLOCK DIAGRAM

Fig. 14

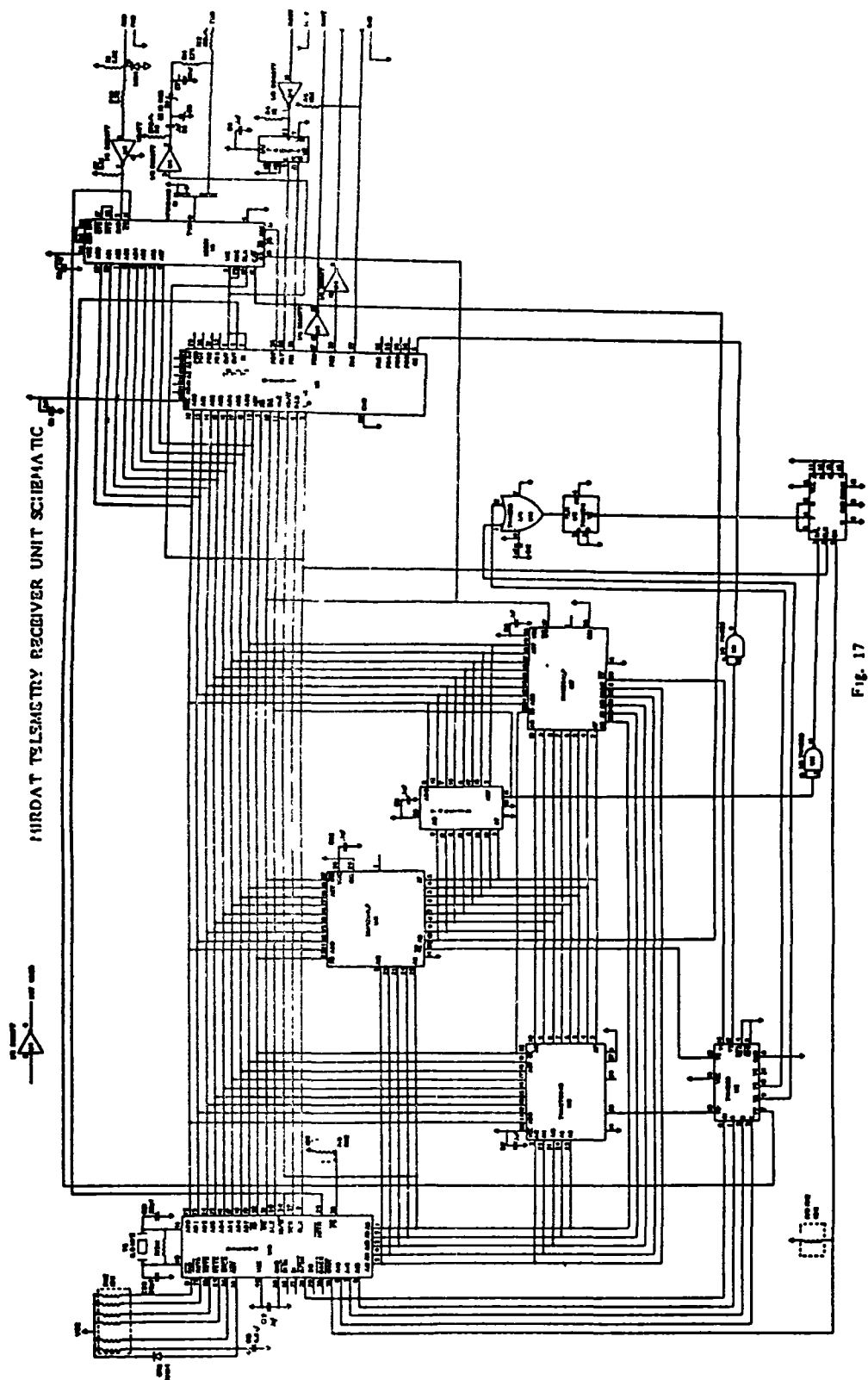


Fig. 17

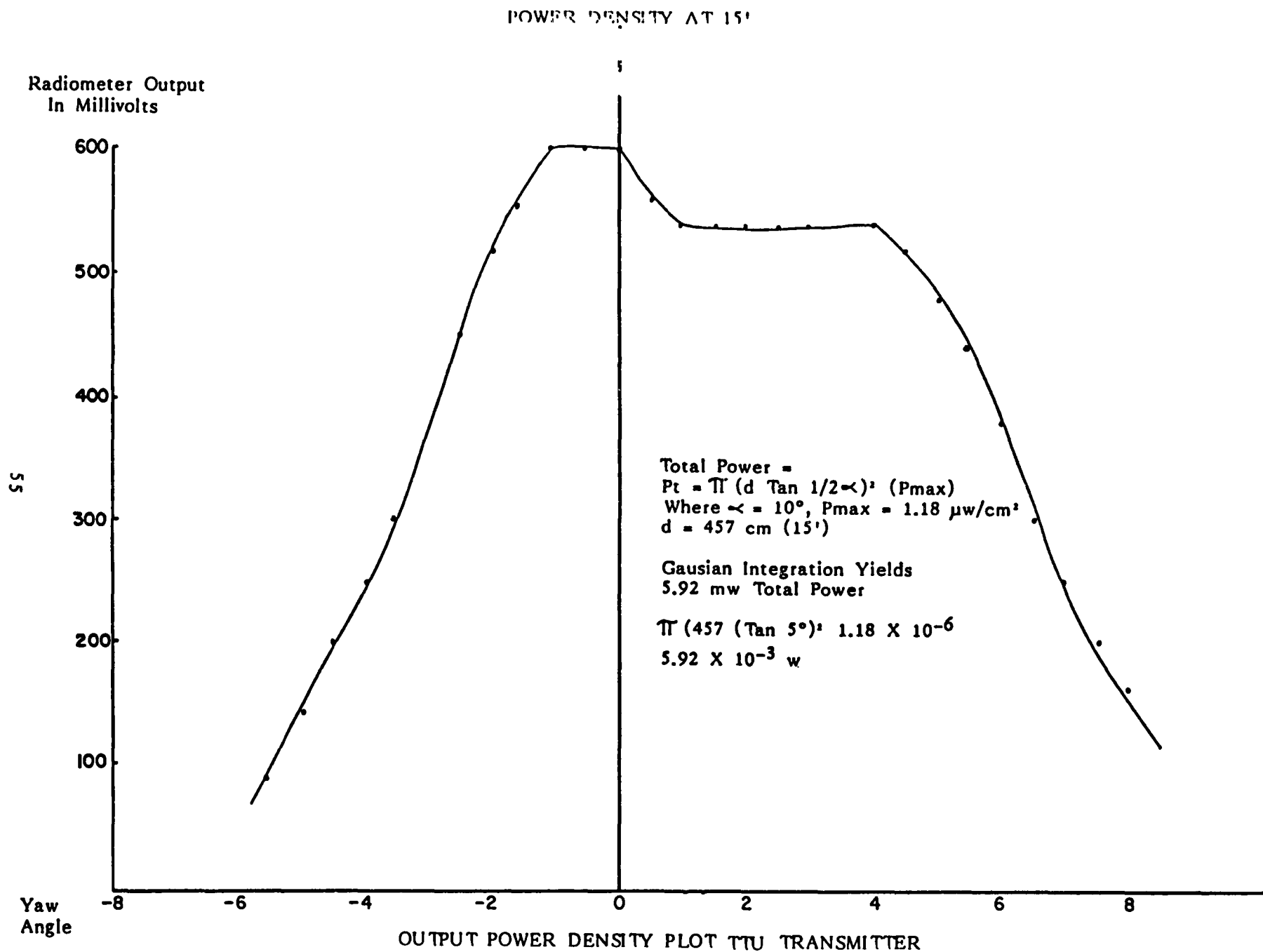


Fig. 18

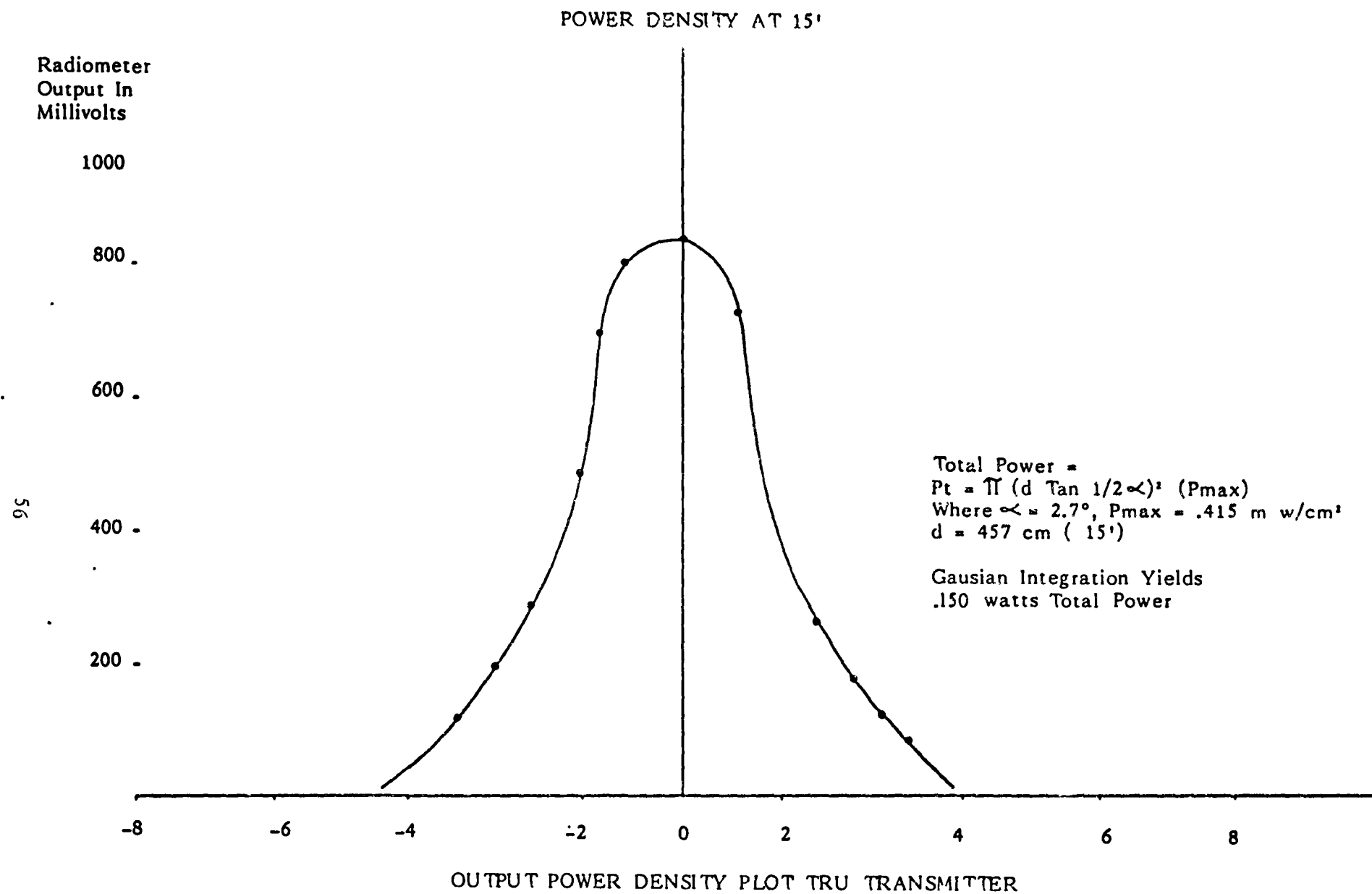


Fig. 19

OBJECT #1 -

6" LONG 1" DIA. SOLID ALUMINUM ROD

OBJECT #2 -

6" LONG 1" OUT. DIA. 0.9" INSIDE DIA. ALUMINUM TUBE

FIND:

1ST MODE NATURAL RESONANCE (MOST PROMINENT)

EQUATION: (FOR LATERAL VIBRATION)

$$\omega_n = (B_n l)^2 \sqrt{EJ / m l^4} = (\text{NATURAL FREQUENCY IN (RAD/SEC)})$$

$$(B_n l)^2 = (\text{EIGENVALUES 1ST MODE, NO UNITS}) \Rightarrow 22.3733$$

$$E = (\text{MODULUS OF ELASTICITY}) = 10 \times 10^6 \text{ lbs/in}^2$$

$$\text{OR: } (10 \times 10^6 \text{ lbs/in}^2) (144 \text{ in}^2/\text{ft}^2) = 1.44 \times 10^9 \text{ lbs/ft}^2 \text{ (IN TERMS OF FEET)}$$

$$\rho - (\text{DENSITY FOR LONGITUDINAL VIBRATIONS}) = 165 \text{ lbs/ft}^3$$

$$\text{VOLUME OF SOLID } (V_s) = 0.0027 \text{ ft}^3$$

$$V_1 = [\pi (0.083^2) / 4] [0.50 \text{ ft}] = 0.0027 \text{ ft}^3$$

$$\text{VOLUME OF TUBE } (V_T) = 0.0005 \text{ ft}^3$$

$$V_2 = 0.0027 - [\pi (0.075^2) / 4] [0.50 \text{ ft}] = 0.0005 \text{ ft}^3$$

$$m_1 - (\text{MASS PER UNIT LENGTH OF SOLID ROD}) = 0.891 \text{ lbs/ft}$$

$$\text{AREA OF SOLID} = 0.0054 \text{ ft}^2$$

$$m = (0.0054 \text{ ft}^2) (165 \text{ lbs/ft}^3) = 0.891 \text{ lbs/ft}$$

$$m_2 - (\text{MASS PER UNIT LENGTH OF TUBE}) = 0.165 \text{ lbs/ft}$$

$$\text{AREA OF TUBE } (0.0054 \text{ ft}^2) - (0.0044 \text{ ft}^2) = 0.001 \text{ ft}^2$$

$$m = (0.001 \text{ ft}^2) (165 \text{ lbs/ft}^3) = 0.165 \text{ lbs/ft}$$

$$I_1 - (\text{MOMENT OF INERTIA, SOLID}) \quad M l^2 / 2 = 1.179 \times 10^{-5} \text{ SLUGS ft}^2$$

$$M (\text{IN SLUGS}) = (0.0027 \text{ ft}^3) (165 \text{ lbs/ft}^3) / 32.2 \text{ ft/sec}^2 = 0.0137 \text{ SLUGS}$$

$$I = M l^2 / 2 = (0.0137) (0.0415)^2 / 2 = 1.179 \times 10^{-5} \text{ SLUGS ft}^2$$

$$I_2 - (\text{MOMENT OF INERTIA, TUBE}) \quad (M/2) (R^2 + r^2) = 3.9 \times 10^{-6} \text{ SLUGS ft}^2$$

$$M (\text{IN SLUGS}) = (0.0005 \text{ ft}^3) (165 \text{ lbs/ft}^3) / 32.2 \text{ ft/sec}^2 = 0.0025 \text{ SLUGS}$$

$$I = [(0.0025) / 2] [(0.0415)^2 + (0.0375)^2] = 3.9 \times 10^{-6} \text{ SLUGS ft}^2$$

FREQUENCY ANALYSIS

Fig. 20

LATERAL VIBRATION (AT 2ND MODE RESONANCE)

$$(SOLID) - \omega_n = (\beta_n L)^2 \sqrt{EI / m L^4}$$

$$\omega_n = (22.3733) \sqrt{\frac{(1.44 \times 10^9 \text{ lbs./ft}^2) (1.179 \times 10^{-5} \text{ SLUGS ft}^2)}{(0.891 \text{ lbs./ft.}) (0.50)^4}}$$

$$\omega_n = 12354.3 \text{ RAD/SEC}$$

$$\omega_n = (12354.3 / 2\pi) = \underline{\underline{1.9 \text{ KHz}}}$$

(TUBE)

$$\omega_n = (22.3733) \sqrt{\frac{(1.44 \times 10^9 \text{ lbs./ft}^2) (3.9 \times 10^{-6} \text{ SLUGS ft}^2)}{(0.165 \text{ lbs./ft}^2) (0.50)^4}}$$

$$\omega_n = 16510.55 \text{ RAD/SEC}$$

$$\omega_n = (16510.55 / 2\pi) = \underline{\underline{2.6 \text{ KHz}}}$$

LONGITUDINAL VIBRATION (AT 1ST MODE RESONANCE)
(SAME FOR SOLID OR TUBE CONFIGURATION)

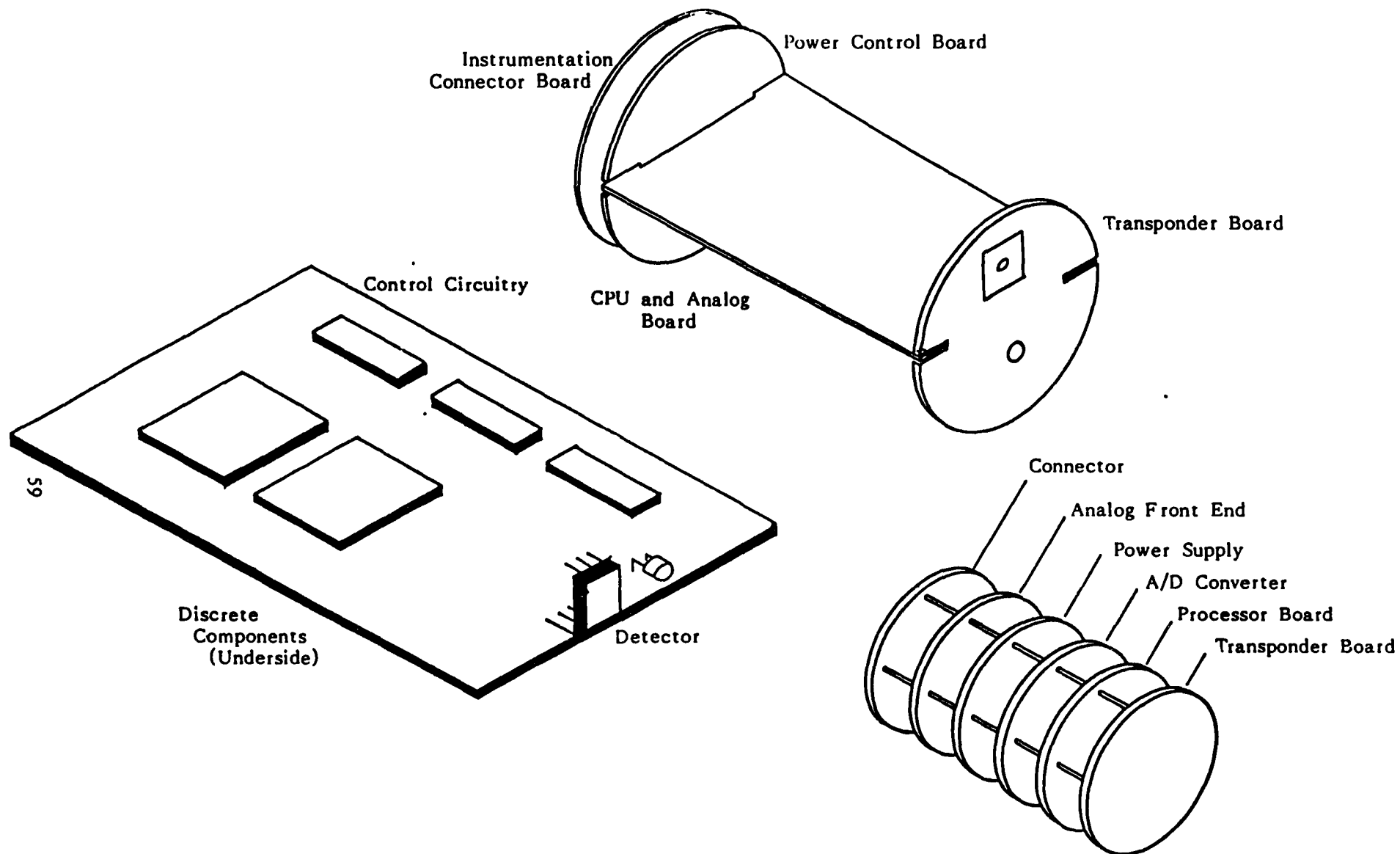
$$\text{EQUATION} = \omega_1 = \pi / L \sqrt{E / \rho}$$

$$\omega_1 = \pi / (0.50) \sqrt{(1.44 \times 10^9 \text{ lbs./ft}^2) / (165 \text{ lbs./ft}^3)}$$

$$\omega_1 = 18561.75 \text{ RAD/SEC}$$

$$\omega_1 = (18561.75 / 2\pi) = \underline{\underline{2.9 \text{ KHz}}}$$

Fig. 20 con't.



CONSTRUCTION TECHNIQUES

Fig. 21

APPENDIX A
SOFTWARE DOCUMENTATION TELEMETRY TRANSMITTER UNIT


```

; ENERGY OPTICS, INCORPORATED
; 524 NORTH CAMPO
; LAS CRUCES, NM. 88001
;
; AUTHOR: R. L. HANSEN
;
; WRITTEN: 05/03/85
;
; DESCRIPTION:
;
; THE NORMAL STATE OF MIRDAT IS ASLEEP. UPON RECEIPT
; OF A HARDWARE DETERMINED NUMBER OF I/R PULSES, POWER
; WILL BE APPLIED AND THE INITIALIZATION PHASE BEGINS.
;
; FIRST ALL RAM IS CLEARED TO A KNOWN STATE OF ZEROS,
; AND ALL PORTS OF THE 8751 ARE INITIALIZED TO ONES.
; AN INTERNAL COUNTER IS SET TO -1 AND EXTERNAL MODE
; SO THAT WHEN THE NEXT I/R BIT IS DETECTED, THE COUNTER
; WILL OVERFLOW CAUSING AN INTERRUPT.
;
; THE INTERRUPT PROCESSING CODE THEN STARTS THE INTERNAL
; TIMER, WHICH WAS PRESET DURING INITIALIZATION TO CAUSE
; AN INTERRUPT EVERY 100 MICROSECONDS, AND FURTHER INTER-
; RPTS FROM THE COUNTER ARE DISABLED. ALL TIMING HERE-
; AFTER WILL BE BASED ON THE INTERNAL TIMER INTERRUPTS.
;
; AFTER SIX (6) BITS, SPACED AT 200 USEC INTERVALS, HAVE
; BEEN SUCCESSFULLY RECEIVED, AND ACKNOWLEDGE SEQUENCE OF
; TWO (2) BITS, SPACED AT 100 USEC INTERVALS, IS TRANS-
; MITTED, 100 USEC AFTER THE SIXTH BIT.
;
; ALL TIMING IS NOW TEMPORARILY HALTED, AND THE ANALOG
; TO DIGITAL CONVERTER IS STARTED. THE RESULTS OBTAINED
; FROM ALL SIXTEEN (16) CHANNELS ARE RECORDED IN LOCAL
; RAM. THE DATA IS THEN RUN THROUGH A HAMMING ALGORITHM
; TO GENERATE A SET OF CHECK BITS TO ENSURE DATA VALIDITY.
;
; THE FOUR (4) HAMMING CHECK (SYNDROME) BITS FOR EACH DATA
; BYTE ARE PACKED INTO EIGHT (8) BIT BYTES AND STORED AT
; THE END OF THE OUTPUT DATA BUFFER.
;
; THE ACCUMULATED DATA IS THEN TRANSMITTED VIA THE I/R
; OPTICAL LINK AS A NINE (9) BIT BYTE (START BIT AND
; EIGHT (8) DATA BITS) AT A RATE OF 100 USEC PER BIT.
; THE SEPERATION BETWEEN THE BYTES IS 300 USECS. THE
; ENTIRE 24 BYTE BUFFER IS TRANSMITTED AS A CONTINUOUS
; STREAM OF DATA.
;
; UPON COMPLETION OF THE TRANSMISSION SEQUENCE, THE
; SYSTEM RETURNS TO A SLEEPING STATE.

```

; BIT CONSTANTS

0060	IPMD	EQU	01100000B	;TIMER 1 (COUNT/MODE 2)
0002	ITMD	EQU	00000010B	;TIMER 0 (TIME/MODE 2)

; OTHER CONSTANTS

0018	BSIZ	EQU	24	;XMIT BUFFER SIZE
0023	BTIM	EQU	35	;DATA BIT TIME (100 USEC)
000F	CHAN	EQU	15	;ADC HIGH CHANNEL
0010	CSIZ	EQU	16	;ADC BUFFER SIZE

; BUFFER ASSIGNMENTS

0060	CBUF	EQU	60H	; (24) ADC DATA BUFFER
007F	RTOP	EQU	7FH	; (127) TOP OF RAM (MSB)
0050	STAF	EQU	50H	; (16) SYSTEM STACK (TOP)

---- ENTRY POINTS ----

```

;      RESET ENTRY POINT

0000      ORG      RESET

0000 020030  RST:   JMP      IPE      ;INITIALIZE PROGRAM


;      EXT - EXTERNAL INTERRUPT

0003      ORG      EXT10

0003 04      EXT:  INC      A      ;SET COMPLETE FLAG
0004 32      RETI


;      TIM - TIMER 0 OVERFLOW INTERRUPT

000B      ORG      TIMER0

000B 04      TIM:  INC      A      ;SET OCCURED FLAG
000C 32      RETI      ;CLEAR STACK


;      CNT - TIMER 1 OVERFLOW INTERRUPT

001B      ORG      TIMER1

001B D28C      CNT:  SETB     TR0      ;START BIT TIMER
001D 04      INC      A
001E 32      RETI      ;CLEAR STACK

```

```

;      BYPASS INTERRUPT AREA

0030      ORG      30H

;      IPE - INITIALIZE PROGRAM FOR EXECUTION

0030 75A800  IPE:   MOV      IE,#0           ;CLEAP INTERPUPTS
0033 758150      MOV      SP,#STAK
0036 787F      MOV      R0,#RTOP
0038 E4        CLP      A

0039 F6        IPE1: MOV      @R0,A           ;CLEAP A BYTE
003A D8FD      DJNZ     R0,IPE1           ; UNTIL DONE

003C 14        DEC      A
003D F580      MOV      P0,A           ;INITIALIZE PORTS
003F F590      MOV      P1,A
0041 F5A0      MOV      P2,A
0043 F5B0      MOV      P3,A
0045 F58D      MOV      TH1,A           ;SET COUNTER INITIAL COUNT
0047 F58B      MOV      TL1,A
0049 74DD      MOV      A,#-BTIM
004B F58C      MOV      TH0,A           ;SET BIT TIMING
004D 2412      ADD      A,#18
004F F58A      MOV      TL0,A           ;SET FIRST BIT
0051 758962     MOV      TMOD,#IRMD OF ITMD
0054 758800     MOV      TCON,#0        ;INITIALIZE TIMERS
0057 D2AB      SETB     ET1             ;ENABLE I/P INTERRUPT
0059 D28E      SETB     TF1             ;ENABLE COUNTER
005B D2AF      SETB     EA             ;ENABLE ALL INTERPUPTS
005D E4        CLP      A
005E 60FE      JZ       $              ;WAIT FOR INTERRUPT

;      WHEN INTEPRUFT OCCUPS, FALL THROUGH TO "ECS"

```

```

;      ECS - ESTABLISH COMMUNICATIONS SYNC
;
;      VERIFIES THAT SIX (6) SYNC BITS ARE RECEIVED
;      AT THE PROPER TIMING INTERVAL.

0060 D2A9      ECS:   SETB     ET0           ;ENABLE TIMER INTERPUPT
0062 C2AB      CLR     ET1           ; BUT NOT I/R INPUT
0064 7B00      MOV     R3,#0         ;PETRY COUNT 256 ;

0066 7A06      ECS1:  MOV     R2,#6         ;BIT COUNTER

0068 74FE      ECS2:  MOV     A,#-2
006A 70FE      JNZ     $             ;WAIT 2 BIT TIMES

006C C28F      CLR     TF1           ;NOW LOOP FOR A BIT
006E 7F02      MOV     R7,#2
0070 DFFE      DJNZ    R7,$          ;DELAY 20 USEC

0072 00        NOP
0073 308F22     JNB     TF1,ECS3       ;IF NO BIT FOUND
0076 DAFO      DJNZ    R2,ECS2       ; ELSE LOOP

0078 E4        CLR     A
0079 60FE      JZ      $             ;WAIT 1 BIT TIME

007B C2B6      CLR     WR           ;XMIT ON
007D D2B6      SETB    WR           ;XMIT OFF
007F E4        CLR     A
0080 60FE      JZ      $             ;WAIT 1 BIT TIME

0082 C2B6      CLR     WR           ;XMIT ON
0084 D2B6      SETB    WR           ;XMIT OFF
0086 75A800     MOV     IE,#0        ;STOP INTERPUPTS
0089 758800     MOV     TCON,#0      ; AND TIMEPS
008C 12009E     CALL    ACD          ;ACCUMULATE A/D DATA
008F 1200B0     CALL    GNC          ;GENERATE CHECK BITS
0092 120100     CALL    TDB          ; AND SEND IT OUT
0095 02009A     JMP     ECS4         ; AND THATS IT

0098 DBCC      ECS3:  DJNZ    R3,ECS1   ;IF MOPE PETPIES

009A C297      ECS4:  CLR     P1.7     ;TURN OFF POWER
009C 80FE      JMP     $             ; AND DIE RIGHT HERE

```

---- COMMON SUBROUTINES ----

```

;      ACD - ACCUMULATE CONVERTER DATA
;
;      OBTAINS ALL 16 CHANNELS OF DATA FROM THE
;      ADC AND SAVES IN LOCAL RAM.
;
;      EXIT      (R0) - BUFFER POINTER

009E D2A8      ACD:      SETB      EX0          ;ENABLE EOC INTERRUPT
00A0 786F      MOV      R0,#CBUF+CSIZ-1 ;BUFFER POINTER
00A2 7A0F      MOV      R2,#CHAN          ;LOOP COUNTER

00A4 1200EC    ACD1:     CALL      RCD          ;GET NEXT CONVERSION
00A7 18        DEC      R0              ; ADJUST POINTER
00A8 DAFA      DJNZ     R2,ACD1          ; UNTIL DONE

00AA 1200EC    CALL      RCD          ;GET FINAL CHANNEL
00AD C2A8      CLR      EX0            ;KILL INTERRUPTS
00AF 22        RET

;
;      GHC - GENERATE HAMMING CODE SYNDROME BITS
;
;      COMPUTES THE HAMMING CODE CHECK (SYNDROME)
;      BITS FOR THE CURRENT DATA BUFFER.  THE SYNDROME BITS
;      ARE ADDED TO THE END OF THE DATA BUFFER.

00B0 7860      GHC:     MOV      R0,#CBUF          ;BUFFER POINTER
00B2 7970      MOV      R1,#CBUF+CSIZ ;CHECK BIT BUFFER
00B4 7A08      MOV      R2,#CSIZ/2 ;LOOP COUNTER

00B6 7B02      GHC1:    MOV      P3,#2 ;INNER LOOP COUNTER
00B8 7C00      MOV      R4,#0 ;CHECK BIT ACCUMULATOR

00BA C3        GHC2:    CLR      C
00BB 74F0      MOV      A,#0F0H
00BD 56        ANL      A,@R0 ;CB1
00BE 20D001    JB       P,GHC3 ;IF ALREADY ODD

00C1 B3        CPL      C
00C2 CC      GHC3:     XCH      A,P4
00C3 33        RLC      A ;ACCUMULATE CB1
00C4 CC      XCH      A,R4
00C5 748E      MOV      A,#8EH
00C7 56        ANL      A,@R0 ;CB2
00C8 20D001    JB       P,GHC4

00CB B3        CPL      C
00CC CC      GHC4:     XCH      A,R4
00CD 33        RLC      A ;ACCUMULATE CB2
00CE CC      XCH      A,R4

```

---- COMMON SUBROUTINES ----

```

00CF 746D      MOV     A,#6DH
00D1 56        ANL     A,@R0          ;CB3
00D2 20D001    JB      P,GHC5

00D5 B3        CPL     C
00D6 CC        GHC5:  XCH     A,R4
00D7 33        RLC     A              ;ACCUMULATE CB3
00D8 CC        XCH     A,R4
00D9 745B      MOV     A,#5BH
00DB 56        ANL     A,@R0          ;CB4
00DC 20D001    JB      P,GHC6

00DF B3        CPL     C
00E0 CC        GHC6:  XCH     A,R4
00E1 33        PLC     A              ;ACCUMULATE CB4
00E2 CC        XCH     A,R4
00E3 08        INC     R0              ;ADVANCE DATA POINTER
00E4 DBD4      DJNZ    R3,GHC2        ; GO FOR NEXT BYTE

00E6 EC        MOV     A,R4
00E7 F7        MOV     @R1,A          ;STORE CHECK BITS
00E8 09        INC     R1
00E9 DACB      DJNZ    R2,GHC1        ; UNTIL DONE

00EB 22        RET

```

```

;      RCD - READ ADC DATA
;
;      INITIATES A CONVERSION SEQUENCE AND
;      STORES THE RESULT.
;
;      ENTRY  (R0) - DATA BUFFER POINTER
;              (R2) - DATA CHANNEL (0 - 15)

```

```

00EC 8A90      PCD:    MOV     P1,R2          ;SET ADC CHANNEL
00EE D2AF      SETB    EA              ;ENABLE INTEPRUPTS
00F0 D294      SETB    P1.4            ;START CONVEPSION
00F2 C294      CLP     P1.4
00F4 E4        CLR     A
00F5 60FE      JZ      $              ;WAIT FOR INTERRUPT

00F7 C2AF      CLR     EA              ;TURN OFF INTERRUPTS
00F9 D295      SETB    P1.5            ;ENABLE OUTPUT
00FB A680      MOV     @R0,P0          ;PEAD/STORE DATA
00FD C295      CLP     P1.5
00FF 22        RET

```

```

;      TDB - TRANSMIT DATA BUFFER
;
;      SENDS THE 24 BYTE DATA BUFFER OVER THE
;      OPTICAL LINK.  EACH BYTE CONSISTS OF A START BIT
;      AND 8 DATA BITS.

0100 74DD      TDB:  MOV     A,#-BTIM
0102 F58C      MOV     TH0,A           ;SET BIT TIMER
0104 F58A      MOV     TL0,A
0106 D2A9      SETB    ET0           ;ENABLE TIMEP INTERRUPT
0108 D28C      SETB    TR0           ;STAPT TIMEP
010A D2AF      SETB    EA           ;ENABLE ALL INTERRUPTS
010C E4        CLR     A
010D 7860      MOV     P0,#CBUF       ;DATA POINTER
010F 7D18      MOV     R5,#BSIZ       ;BUFFERP SIZE

0111 7E08      TDB1:  MOV     R6,#8           ;BIT COUNTER
0113 60FE      JZ      $             ;WAIT FOR BIT TIME
0115 C2B6      CLR     WR
0117 D2B6      SETB    WP           ;SEND STAPT BIT

0119 E6        TDB2:  MOV     A,@R0           ;GET DATA BYTE
011A 03        RR      A             ;LSB TO MSB
011B FE        MOV     @R0,A         ;PESTOPE
011C 20E706     JB      ACC.7,TDB3      ;IF LSB = 1
011F E4        CLR     A
0120 60FE      JZ      $             ;WAIT FOR BIT TIME
0122 02012C     JMP     TDB4

0125 E4        TDB3:  CLP     A
0126 60FE      JZ      $             ;WAIT FOR BIT TIME
0128 C2B6      CLR     WP           ;SEND A BIT
012A D2B6      SETB    WP

012C DEEB      TDB4:  DJNZ    R6,TDB2      ;LOOP FOR NEXT BIT
012E 03        INC     P0           ;ADVANCE DATA POINTER
012F 74FE      MOV     A,#-2
0131 70FE      JNZ     $             ;WAIT INTERBYTE GAP
0133 DDDC      DJNZ    R5,TDB1      ;LOOP FOR NEXT BYTE

0135 75A800     MOV     IE,#0         ;STOP INTEPPUPTS
0138 758800     MOV     TCON,#0       ; AND TIMEPS
013B 22        PET

0000          END

```


---- SYMBOL TABLE ----

ACC	00E0	GHC1	00B6	STAK	0050
ACD	009E	GHC2	00BA	TCON	0088
ACD1	00A4	GHC3	00C2	TDB	0100
BSIZ	0018	GHC4	00CC	TDB1	0111
BTIM	0023	GHC5	00D6	TDB2	0119
CBUF	0060	GHC6	00E0	TDB3	0125
CHAN	000F	IE	00A8	TDB4	012C
CNT	001B	IPE	0030	TF1	008F
CSIZ	0010	IPE1	0039	TH0	008C
EA	00AF	IRMD	0060	TH1	008D
ECS	0060	ITMD	0002	TIM	000B
ECS1	0066	P	00D0	TIMER0	000B
ECS2	0068	P0	0080	TIMER1	001B
ECS3	0098	P1	0090	TL0	008A
ECS4	009A	P2	00A0	TL1	008B
ET0	00A9	P3	00B0	TMOD	0089
ET1	00AB	RCD	00EC	TP0	008C
EX0	00AB	RESET	0000	TR1	008E
EXT	0003	RST	0000	WR	00B6
EXTI0	0003	RTOP	007F		
GHC	00B0	SP	00B1		

APPENDIX B

SOFTWARE DOCUMENTATION TELEMETRY RECEIVER UNIT

TITLE TRUOS - TELEMETRY RECEIVER UNIT OPERATING SYSTEM

.Z80

```

; TRUOS - TELEMETRY RECEIVER UNIT OPERATING SYSTEM
;
; ENERGY OPTICS, INC.
; 224 NORTH CAMPO
; LAS CRUCES, NM. 88001
;
; AUTHOR: R. L. HANSEN
; WRITTEN: 04/30/85
;
; TRUOS - IS AN OPERATING SYSTEM DESIGNED THE COMMUNICATE
; WITH AND RECEIVED TELEMETRY DATA FROM THE "MIRDAT" TELE-
; METRY DEVICE.

```

; SYSTEM CONSTANTS

0010	BSIZ	EQU	16	;STANDARD BLOCK SIZE
0006	CSIZ	EQU	6	;COMMAND BUFFER SIZE
0008	HSIZ	EQU	BSIZ/2	;HAMMING CODE BUFFER SIZE
607E	STAK	EQU	607EH	;TOP OF SYSTEM STACK

; I/O DEFINITIONS

6100	APRT	EQU	6100H	;NSC800 PORT A ADDRESS
6104	ADDR	EQU	APRT+4	;PORT A DATA DIR REG
6109	BCLR	EQU	APRT+9	;PORT B CLEAR BIT
610D	BSET	EQU	APRT+13	;PORT B SET BIT
610A	CCLR	EQU	APRT+10	;PORT C CLEAR BIT
610E	CSET	EQU	APRT+14	;PORT C SET BIT
0002	SIDR	EQU	00000010B	;SERIAL INPUT DATA REQ
E000	SIOD	EQU	0E000H	;SERIAL DATA PORT
E001	SIOS	EQU	SIOD+1	;SERIAL STATUS PORT
0001	STDR	EQU	00000001B	;SERIAL OUTPUT DATA REQ

; SIO PORT COMMANDS

0040	SIIR	EQU	40H	;INTERNAL RESET
0080	SIXR	EQU	80H	;EXTERNAL RESET

; PORT "C" COMMANDS

0002	RECV	EQU	00000010B	;RECEIVER CLR BIT
0001	XMIT	EQU	00000001B	;TRANSMIT BIT

; TIMER 0 - BAUD RATE GENERATOR

6115	TBRG	EQU	APRT+21	;GENERATOR START
6114	TBR5	EQU	APRT+20	;GENERATOR STOP
6110	TDIV	EQU	APRT+16	;GENERATOR MODULUS REG
6118	TMOD	EQU	APRT+24	;GENERATOR MODE REG

; TIMER 1 - INTERRUPT TIMER

6112	IDIV	EQU	APRT+18	;TIMER DIVIDER
6119	IMOD	EQU	APRT+25	;TIMER MODE
6116	ISTP	EQU	APRT+22	;TIMER STOP
6117	ISTR	EQU	APRT+23	;TIMER START

; ASCII CHARACTER DEFINITIONS

0008	BS	EQU	08H	;BACKSPACE
000D	CR	EQU	0DH	;RETURN
0004	EOT	EQU	04H	;END OF TEXT
001B	ESC	EQU	1BH	;ESCAPE
000A	LF	EQU	0AH	;LINE FEED
001F	NL	EQU	1FH	;NEW LINE
0001	SOM	EQU	01H	;START OF MESSAGE
0003	STX	EQU	03H	;START OF TEXT

SUBTTL ---- INITIALIZATION ----
PAGE

```

;      INITIALIZATION

;      RST - RESTART/POWER UP ENTRY POINT

0000'   F3      RST:  DI      ;ENSURE INTERRUPTS OFF
0001'   31 607E      LD      SP,STAK      ;SET STACK POINTER

;      INITIALIZE PORTS

0004'   21 6104      LD      HL,ADDR
0007'   36 00      LD      (HL),0      ;PORT A ALL INPUT
0009'   23      INC      HL
000A'   36 FF      LD      (HL),0FFH      ;PORT B ALL OUTPUT
000C'   23      INC      HL
000D'   36 2F      LD      (HL),00101111B ;PORT C 0-3 AND TIMER 1 OUTPUT
000F'   23      INC      HL
0010'   36 00      LD      (HL),0      ;ALL PORTS BASIC I/O

;      INITIALIZE BAUD RATE GENERATOR

0012'   21 6118      LD      HL,TMOD
0015'   36 05      LD      (HL),00000101B ;TO - SQUARE WAVE MODE
0017'   21 000C      LD      HL,12
001A'   22 6110      LD      (TDIV),HL      ;TO - DIVISOR (153.6 KHZ)
001D'   32 6115      LD      (TBRG),A      ; AND START TIMER 0

;      CLEAR SYSTEM RAM

0020'   21 0000"      LD      HL,CBUF
0023'   11 0001"      LD      DE,CBUF+1
0026'   01 3FFF      LD      BC,16*1024-1
0029'   36 00      LD      (HL),0
002B'   ED B0      LDIR      ;CLEAR RAM

;      POWER UP RS-232 POWER

002D'   3E 60      LD      A,01100000B
002F'   32 610D      LD      (BSET),A      ;POWER UP 12 VOLTS
0032'   18 10      JR      CIN      ;SKIP INTERRUPT AREA

;      TIMER 1 INTERRUPT AREA

0034'      DS      RST++38H-$      ;LOCATE INTERRUPT

0038'   32 6116      INT: LD      (IPTP),A      ;STOP THE TIMER
003B'   31 607E      LD      SP,STAK      ;CLEAR UP THE STACK
003E'   21 03A4'      LD      HL,TMSG      ; " * INTERRUPT * "
0041'   C3 032F'      JP      TEM1      ;SEND MESSAGE

```

PAGE

```

;      CONTINUE INITIALIZATION

0044'  3E 64      CIN:  LD      A,100
0046'  CD 027F'   CALL    MSD          ;WAIT FOR STABLE POWER

;      INITIALIZE CONTROL LINES

0049'  3E 03      LD      A,RECV+XMIT
004B'  32 610A    LD      (CCLR),A      ;SET UP CONTROL LINES

;      INITIALIZE USART

004E'  3E 80      LD      A,SIXR
0050'  32 610D    LD      (BSET),A      ;RESET USART
0053'  3E 0A      LD      A,10
0055'  CD 027F'   CALL    MSD
0058'  3E 80      LD      A,SIXR
005A'  32 6109    LD      (BCLR),A      ;CLEAR RESET
005D'  AF         XOR      A
005E'  32 E001    LD      (SIOS),A
0061'  32 E001    LD      (SIOS),A      ;CLEAR BUFFERS
0064'  32 E001    LD      (SIOS),A
0067'  3E 40      LD      A,SIIR
0069'  32 E001    LD      (SIOS),A      ;DO INTERNAL RESET
006C'  E5         PUSH    HL
006D'  E1         POP     HL          ;SMALL DELAY
006E'  3E 4E      LD      A,01001110B
0070'  32 E001    LD      (SIOS),A      ;16X, 8BIT, NOP, 1STOP
0073'  3E 27      LD      A,00100111B
0075'  32 E001    LD      (SIOS),A      ;XMIT/RECV ENABLE, DTR/RTS
0078'  3A E000    LD      A,(SIOD)
007B'  3A E000    LD      A,(SIOD)      ;CLEAR RECEIVE BUFFER
007E'  21 010A    LD      HL,10AH
0081'  22 0037"   LD      (CCNT),HL      ;SET DEFAULT TIME
0084'  22 0039"   LD      (CTIM),HL

```

SUBTTL ---- MAIN PROGRAM ----
 PAGE

```

;      MAIN PROGRAM LOOP
;
;      WE LOOP HERE WAITING FOR A COMMAND FROM
;      THE TERMINAL OPERATOR.

0087'   FD 21 0039"      MCL:   LD     IY,CTIM      ;SET INTERVAL TIMER
008B'   21 0000"        LD     HL,CBUF
008E'   F3              DI             ;ENSURE NO INTERRUPTS
008F'   22 0035"        LD     (BPTR),HL
0092'   36 FF          LD     (HL),OFFH      ;SET INVALID BUFFER

0094'   3A 003C"      MCL1:  LD     A,(TFLG)
0097'   B7            OR     A
0098'   CA 00AC'      JP     Z,MCL2          ;IF NOT IN TEST MODE

009B'   3E 64          LD     A,100
009D'   CD 027F'      CALL    MSD           ;DELAY 100 MSEC
00A0'   FD 35 00      DEC     (IY)
00A3'   C2 00AC'      JP     NZ,MCL2        ;IF NOT TIME

00A6'   FD 35 01      DEC     (IY+1)
00A9'   CA 0126'      JP     Z,ROD          ;IF TIME TO TEST

00AC'   3A E001      MCL2:  LD     A,(SIOS)
00AF'   E6 02      AND     SIDR
00B1'   CA 0094'      JP     Z,MCL1          ;IF NO INPUT DATA REQUEST

00B4'   3A E000      LD     A,(SIOD)        ;READ BYTE
00B7'   FE 1B      CP     ESC
00B9'   CA 0000'      JP     Z,RST          ;IF RESET COMMAND

00BC'   21 0000"      LD     HL,CBUF
00BF'   34          INC     (HL)
00C0'   35          DEC     (HL)
00C1'   F2 00CB'      JP     P,MCL3        ;IF VALID BUFFER

00C4'   FE 03      CP     STX
00C6'   C2 0094'      JP     NZ,MCL1        ;IF NOT START OF COMMAND

00C9'   3E 24      LD     A,'$'

00CB'   FE 0D      MCL3:  CP     CR
00CD'   CA 0104'      JP     Z,MCL5        ;IF COMMAND TERMINATE

00D0'   FE 08      CP     BS
00D2'   CA 00E6'      JP     Z,MCL4        ;IF BACKSPACE

00D5'   CD 031E'      CALL    STC           ;ECHO CHARACTER
00D8'   2A 0035"      LD     HL,(BPTR)
00DB'   77          LD     (HL),A          ;STOW IN BUFFER
00DC'   23          INC     HL
00DD'   22 0035"      LD     (BPTR),HL      ;UPDATE POINTER
00E0'   7D          LD     A,L
00E1'   FE 06      CP     CSIZ

```

00E3' C2 0094' JP NZ,MCL1 ;IF BUFFER NOT FULL

; BACKSPACE COMMAND BUFFER

```

00E6' 2A 0035" MCL4: LD HL,(BPTR)
00E9' 7D LD A,L
00EA' B7 OR A
00EB' CA 0087' JP Z,MCL ;IF AT START OF LINE

00EE' 2B DEC HL
00EF' 22 0035" LD (BPTR),HL ;BACKOFF POINTER
00F2' 3E 08 LD A,BS
00F4' CD 031E' CALL STC ;BACKSPACE TERMINAL
00F7' 3E 20 LD A,' '
00F9' CD 031E' CALL STC ;CLEAR DISPLAY CHAR
00FC' 3E 08 LD A,BS
00FE' CD 031E' CALL STC ;POSITION CURSOR
0101' C3 0094' JP MCL1 ; AND LOOP
  
```

; INTERPRET COMMAND

```

0104' 3E 1F MCL5: LD A,NL
0106' CD 031E' CALL STC ;SEND ACKNOWLEDGE TO TERM
0109' 11 0001" LD DE,CBUF+1
010C' 1A LD A,(DE) ;GET COMMAND
010D' FE 30 CP '0'
010F' CA 0150' JP Z,SCT ;IF SET CYCLE TIME

0112' FE 31 CP '1'
0114' CA 017B' JP Z,STM ;IF START TEST

0117' FE 32 CP '2'
0119' CA 011F' JP Z,CTM ;IF STOP TEST

011C' C3 032C' JP TEM ;SEND ERROR MESSAGE
  
```

SUBTTL ---- COMMAND PROCESSORS ----
 PAGE


```

;      CTM - CLEAR TEST MODE
;
;      CLEARS THE TEST MODE FLAG

```

```

011F'  AF
0120'  32 003C"
0123'  C3 0087'

CTM:   XOR    A
      LD      (TFLG),A
      JP      MCL          ;BACK TO MAIN LOOP

```

```

;      ROD - READ OPTICAL DATA
;
;      READS A BUFFER FULL OF DATA FROM MIRDAT.

```

```

0126'  2A 0037"
0129'  22 0039"
012C'  CD 01FC'
012F'  CD 030B'
0132'  3E 03
0134'  CD 027F'
0137'  11 0008"
013A'  06 18

013C'  CD 0299'
013F'  12
0140'  13
0141'  10 F9

0143'  32 6116
0146'  F3
0147'  CD 033C'
014A'  CD 02D4'
014D'  C3 0087'

ROD:   LD      HL,(CCNT)      ;RESET TIMER
      LD      (CTIM),HL
      CALL    ECS            ;GET IN SYNC
      CALL    SIT            ;INITIALIZE INTERRUPT
      LD      A,3
      CALL    MSD            ;DELAY 3 MSEC
      LD      DE,RBUF        ;DATA BUFFER POINTER
      LD      B,BSIZ+HSIZ    ;BLOCK SIZE COUNTER

ROD1:  CALL    RDB            ;GET NEXT DATA BYTE
      LD      (DE),A         ;STORE IT
      INC     DE              ;ADVANCE POINTER
      DJNZ    ROD1           ;UNTIL BLOCK RECEIVED

      LD      (ISTP),A        ;STOP TIMER
      DI
      CALL    VDB            ;VALIDATE DATA BUFFER
      CALL    SBT            ;SEND BUFFER TO TERMINAL
      JP      MCL            ;BACK TO MAIN LOOP

```

```

;      SCT - SET CYCLE TIME
;
;      ASSEMBLES INPUT CYCLE TIME, CONVERTS
;      IT TO BINARY AND STORES IN "CCNT".

```

```

0150'  06 03
0152'  21 0000

0155'  13
0156'  1A
0157'  FE 0D
0159'  CA 0174'

015C'  D6 30
015E'  DA 032C'

0161'  FE 0A
0163'  D2 032C'

SCT:   LD      B,3            ;MAXIMUM COUNT
      LD      HL,0            ;ASSEMBLY BUFFER

SCT1:  INC     DE              ;ADVANCE INPUT POINTER
      LD      A,(DE)          ;GET NEXT CHAR
      CP      CR
      JP      Z,SCT2          ;IF END OF COMMAND

      SUB     '0'
      JP      C,TEM           ;IF NOT DECIMAL DIGIT

      CP      10
      JP      NC,TEM          ;IF NOT DECIMAL DIGIT

```

```

0166'  D5          PUSH    DE
0167'  29          ADD     HL,HL          ;#2
0168'  54          LD      D,H
0169'  5D          LD      E,L
016A'  29          ADD     HL,HL          ;#4
016B'  29          ADD     HL,HL          ;#8
016C'  19          ADD     HL,DE          ;#10
016D'  16 00       LD      D,0
016F'  5F          LD      E,A          ;NEW DIGIT
0170'  19          ADD     HL,DE
0171'  D1          POP     DE
0172'  10 E1       DJNZ    SCT1          ;UNTIL DONE
  
```

```

0174'  24          SCT2: INC     H
0175'  22 0037"    LD      (CCNT),HL      ;SET COUNTER
0178'  C3 0087'    JP      MCL          ; AND RETURN
  
```

```

;      STM - START TEST MODE
;
;      SETS TEST MODE FLAG AND INTIALIZES
;      TESTING.
  
```

```

017B'  32 003C"    STM:  LD      (TFLG),A      ;SET FLAG
017E'  C3 0126'    JP      ROD          ; AND INITIALIZE TESTING
  
```

SUBTTL ---- SUBROUTINES ----
 PAGE

```

;      DCN - DISPLAY CHANNEL NUMBER
;
;      CONVERTS VALUE TO DECIMAL VALUE AND
;      SENDS TO THE TERMINAL
;
;      ENTRY  (A) - VALUE

0181'  21 003B"      DCN:  LD      HL,TEMP
0184'  C6 01          ADD      A,1          ;CHAN 1..16
0186'  27            DAA
0187'  77            LD      (HL),A
0188'  CD 018B'      CALL     DCN1          ;DISPLAY UPPER DIGIT

018B'  3E 30          DCN1: LD      A,'0'          ;CONVERT TO ASCII
018D'  ED 6F          RLD
018F'  CD 031E'      CALL     STC          ;DISPLAY DIGIT
0192'  C9            RET

;      DDV - DISPLAY DECIMAL VALUE
;
;      CONVERTS INPUT VALUE TO A FRACTIONAL
;      DECIMAL VOLTAGE IN THE RANGE 0 - 5 VOLTS, AND
;      SENDS THE RESULT TO THE TERMINAL.
;
;      ENTRY  (A) - INPUT VALUE

0193'  D5            DDV:  PUSH     DE          ;SAVE REGISTERS
0194'  C5            PUSH     BC
0195'  11 00C4        LD      DE,196          ;CONVERSION VALUE
0198'  21 0000        LD      HL,0           ;INITIALIZE RESULT
019B'  06 08          LD      B,8           ;LOOP COUNT
019D'  F5            PUSH     AF          ;SAVE INPUT

019E'  CB 3F          DDV1: SRL      A          ;LSB TO CY
01A0'  D2 01A4'      JP      NC,DDV2        ;IF NO BIT

01A3'  19            ADD      HL,DE          ;ADD MULTIPLIER

01A4'  EB            DDV2:  EX      DE,HL
01A5'  29            ADD      HL,HL          ;SHIFT MULTIPLIER
01A6'  EB            EX      DE,HL
01A7'  10 F5          DJNZ     DDV1          ;IF MORE BITS

01A9'  F1            POP      AF
01AA'  B7            OR      A
01AB'  F2 01B2'      JP      P,DDV3        ;IF < 2.5 VOLTS

01AE'  11 0014        LD      DE,20          ;ROUND UP
01B1'  19            ADD      HL,DE

01B2'  DD 21 03B7'    DDV3:  LD      IX,DDVT          ;DIVISOR TABLE
01B6'  FD 21 0030"    LD      IY,RSLT        ;RESULT POINTER

```

```

01BA' DD 5E 00      DDV4: LD    E,(IX)
01BD' DD 23          INC    IX
01BF' DD 56 00      LD    D,(IX)      ;GET NEXT DIVISOR
01C2' DD 23          INC    IX
01C4' 7A            LD    A,D
01C5' B3            OR     E
01C6' CA 01DC'      JP    Z,DDV7      ;IF ALL DONE
01C9' 97            SUB    A          ;CLEAR QUOTIENT

01CA' ED 52          DDV5: SBC    HL,DE      ;TRIAL DIVIDE
01CC' DA 01D3'      JP    C,DDV6      ;IF NO GO

01CF' 3C            INC    A          ;COUNT IT
01D0' C3 01CA'      JP    DDV5        ; AND LOOP

01D3' 19            DDV6: ADD    HL,DE      ;RESTORE VALUE
01D4' FD 77 00      LD    (IY),A      ;SAVE DIGIT
01D7' FD 23          INC    IY
01D9' C3 01BA'      JP    DDV4        ; AND LOOP

01DC' FD 75 00      DDV7: LD    (IY),L      ;SAVE LSD
01DF' 21 0030''     LD    HL,RSLT      ;RESULT POINTER
01E2' 3E 30          LD    A, 0'
01E4' 86            ADD    A,(HL)      ;GET UNITS
01E5' 23            INC    HL
01E6' CD 031E'      CALL    STC        ;DISPLAY IT
01E9' 3E 2E          LD    A,'.'
01EB' CD 031E'      CALL    STC        ;DISPLAY POINT
01EE' 06 03          LD    B,3

01F0' 3E 30          DDV8: LD    A,'0'
01F2' 86            ADD    A,(HL)      ;CONVERT TO DECIMAL
01F3' 23            INC    HL
01F4' CD 031E'      CALL    STC        ;DISPLAY VALUT
01F7' 10 F7          DJNZ    DDV8      ; AND LOOP

01F9' C1            POP    BC          ;RESTORE REGISTERS
01FA' D1            POP    DE
01FB' C9            RET

```

```

;      ECS - ESTABLISH COMMUNICATIONS SYNC
;
;      SENDS A SERIES OF BITS SPACED AT 200 USEC
;      INTERVALS, LOOKING FOR A SYNC ACKNOWLEDGE BETWEEN
;      EACH BIT.
;
;      << INSTRUCTION TIMING IS CRITICAL! DO NOT CHANGE >>
;      << TIMING IS DEPENDENT ON A 8.0 MHZ XTAL>>

```

```

01FC' 21 6100      ECS:  LD    HL,APRT      ;INPUT BIT POINTER
01FF' 3E 02          LD    A,RECV

0201' 3E 01          ECS1: LD    A,XMIT

```

```

0203' 32 610E      LD      (CSET),A      ;BIT ON
0206' 32 610A      LD      (CCLR),A      ;BIT OFF
0209' 06 1F        LD      B,31
020B' 10 FE        DJNZ    $              ;DELAY 90 USEC

020D' 3E 02        LD      A,RECV
020F' 32 610E      LD      (CSET),A      ;OPEN RECEIVE WINDOW
0212' 06 05        LD      B,5
0214' 10 FE        DJNZ    $              ;DELAY 20 USEC

0216' ED 57        LD      A,I
0218' B6           OR      (HL)          ;GET INPUT
0219' 32 610A      LD      (CCLR),A      ;CLOSE THE WINDOW
021C' FA 0230'     JP      M,ECS3        ;IF BIT PRESENT

021F' 06 0F        ECS2: LD      B,15
0221' 10 FE        DJNZ    $              ;DELAY 90 USEC
0223' 13           INC      DE
0224' 1B           DEC      DE
0225' 3A E001      LD      A,(SIOS)      ;GET SERIAL STATUS
0228' E6 02        AND      SDR
022A' CA 0201'     JP      Z,ECS1        ;IF NO ABORT REQUEST

022D' C3 0000'     JP      RST          ;(( ABORT ))

0230' 3E 00        ECS3: LD      A,0
0232' ED 44        NEG
0234' 06 14        LD      B,20          ;TIME USER UPPER
0236' 10 FE        DJNZ    $              ;DELAY 80 USEC

0238' 3E 02        LD      A,RECV
023A' 32 610E      LD      (CSET),A      ;OPEN WINDOW
023D' 06 05        LD      B,5
023F' 10 FE        DJNZ    $              ;DELAY 20 USEC

0241' ED 57        LD      A,I
0243' B6           OR      (HL)
0244' 32 610A      LD      (CCLR),A      ;CLOSE WINDOW
0247' F2 021F'     JP      P,ECS2        ;IF BIT IS NOT PRESENT

024A' C9           RET                  ; ELSE RETURN

```

```

;      GCB - GENERATE CORRECTION BIT
;
;      COMPUTES THE BIT VALUE WHICH MUST BE CORRECTED
;
;      ENTRY  (A) - SYNDROME ERROR BITS
;
;      EXIT   (C) - CORRECTION BIT VALUE

```

```

024B' E5           GCB:  PUSH    HL
024C' D5           PUSH    DE
024D' 16 00        LD      D,0
024F' 5F           LD      E,A          ;OFFSET VALUE

```

```

0250' 21 03C1' LD HL,STBL ;TABLE POINTER
0253' 19 ADD HL,DE
0254' 4E LD C,(HL) ;CORRECT BIT VALUE
0255' D1 POP DE
0256' E1 POP HL
0257' C9 RET
  
```

```

;
;
;      COMPUTES THE HAMMING SYNDROME BITS FOR A SUPPLIED
;      BYTE OF DATA.
;
;      ENTRY   (C) - DATA BYTE
;
;      EXIT    (C) - SYNDROME BITS (MSB)
  
```

```

0258' C5      GHC: PUSH BC
0259' 06 00 LD B,0 ;INITIALIZE SYNDROME BITS
025B' 3E F0 LD A,0F0H
025D' A1 AND C ;CHECK SB4
025E' E2 0263' JP PO,GHC1
  
```

```

0261' CB D8      GHC1: SET 3,B
0263' 3E 8E LD A,8EH
0265' A1 AND C ;CHECK SB3
0266' E2 026B' JP PO,GHC2
  
```

```

0269' CB D0      GHC2: SET 2,B
026B' 3E 6D LD A,6DH
026D' A1 AND C ;CHECK SB2
026E' E2 0273' JP PO,GHC3
  
```

```

0271' CB C8      GHC3: SET 1,B
0273' 3E 5B LD A,5BH
0275' A1 AND C ;CHECK SB1
0276' E2 027B' JP PO,GHC4
  
```

```

0279' CB C0      GHC4: SET 0,B
027B' 78 LD A,B ;GET RESULT
027C' C1 POP BC
027D' 4F LD C,A
027E' C9 RET
  
```

```

;
;
;      MSD - MILLISECOND DELAY
;
;      AN INLINE DELAY OF "n" MILLISECONDS.
;
;      ENTRY   (A) - MILLISECOND COUNTER
  
```

```

027F' C5      MSD: PUSH BC
0280' 0E 03 MSD1: LD C,3 ;LOOP COUNTER
  
```

```

0282' 06 64          MSD2: LD      B,100
0284' 10 FE          DJNZ     $

0286' 0D             DEC      C
0287' C2 0282'       JP       NZ,MSD2          ;IF NOT 1 MILLISECOND

028A' 3D             DEC      A
028B' CA 0297'       JP       Z,MSD3          ;IF COUNT EXPIRED

028E' 06 00          LD       B,0
0290' 06 00          LD       B,0          ;EVEN OUT TIMING
0292' 0E 00          LD       C,0
0294' C3 0280'       JP       MSD1          ; AND LOOP

0297' C1             MSD3: POP     BC
0298' C9             RET

; RDB - READ DATA BYTE
;
; READS A BYTE OF DATA FROM THE OPTICAL
; INTERFACE
;
; (< INSTRUCTION TIMING IS CRITICAL! DO NOT CHANGE >)
; (< TIMING IS DEPENDENT ON 8.0 MHZ XTAL >)

0299' D9             RDB:  EXX          ;SAVE USER REGISTERS
029A' 16 00          LD       D,0          ;CLEAR ASSEMBLY BUFFER
029C' 21 6100        LD       HL,APRT      ;INPUT POINTER
029F' 0E 08          LD       C,8          ;BIT COUNTER
02A1' 3E 02          LD       A,RECV
02A3' 32 610E        LD       (CSET),A     ;OPEN WINDOW

02A6' B6             RDB1:  OR        (HL)
02A7' F2 02A6'       JP       P,RDB1      ;WAIT FOR START BIT

02AA' 3E 02          LD       A,RECV
02AC' 32 610A        LD       (CCLR),A     ;CLOSE WINDOW
02AF' 06 17          LD       B,23
02B1' 10 FE          DJNZ     $           ;DELAY 90 USEC

02B3' ED 57          LD       A,I

02B5' 3E 02          RDB2:  LD       A,RECV
02B7' 32 610E        LD       (CSET),A     ;OPEN WINDOW
02BA' 06 04          LD       B,4
02BC' 10 FE          DJNZ     $           ;DELAY 20 USEC

02BE' ED 57          LD       A,I
02C0' B6             OR        (HL)        ;GET BIT
02C1' 32 610A        LD       (CCLR),A     ;CLOSE WINDOW

02C4' 17             RLA                ;BIT TO CY
02C5' CB 1A          RR         D          ;ASSEMBLE BIT

```

```

02C7' 06 14      LD      B,20
02C9' 10 FE      DJNZ    $          ;DELAY

02CB' 13         INC     DE
02CC' 1B         DEC     DE
02CD' 0D         DEC     C
02CE' C2 02B5'   JP      NZ,RDB2      ;IF MORE BITS

02D1' 7A         LD      A,D          ;GET BYTE
02D2' D9         EXX          ;RESTORE USER REGISTERS
02D3' C9         RET

```

```

;      SBT - SEND BUFFER TO TERMINAL
;
;      FORMATS BUFFER FULL OF DATA AND SENDS
;      IT TO THE TERMINAL.

```

```

02D4' 3E 1F      SBT:   LD      A,NL
02D6' CD 031E'   CALL    STC          ;SEND START OF MSG
02D9' 11 0008"   LD      DE,RBUF
02DC' 06 10      LD      B,16      ;CHANNEL COUNTER
02DE' 0E 00      LD      C,0       ;CHANNEL NUMBER

02E0' 79         SBT1:  LD      A,C          ;GET CHANNEL NUMBER
02E1' CD 0181'   CALL    DCM          ; AND DISPLAY IT
02E4' 3E 20      LD      A,' '
02E6' CD 031E'   CALL    STC          ;SPACE
02E9' 1A         LD      A,(DE)      ;GET CHANNEL DATA
02EA' 13         INC     DE
02EB' CD 0193'   CALL    DDV          ;DISPLAY DECIMAL VALUE
02EE' 2A 003D"   LD      HL,(VFLG)
02F1' 29         ADD     HL,HL        ;SHIFT VALID DATA FLAG
02F2' 22 003D"   LD      (VFLG),HL
02F5' D2 02FD'   JP      NC,SBT2      ;IF DATA WAS VALID

02F8' 3E 2A      LD      A,'*'
02FA' CD 031E'   CALL    STC          ;DISPLAY ERROR

02FD' 3E 1F      SBT2:  LD      A,NL
02FF' CD 031E'   CALL    STC          ;TERMINATE LINE
0302' 0C         INC     C            ;ADVANCE CHANNEL
0303' 10 DB      DJNZ    SBT1        ; AND LOOP

0305' 3E 1F      LD      A,NL
0307' CD 031E'   CALL    STC          ;TERMINATE MESSAGE
030A' C9         RET

```

```

;      SIT - SET INTERRUPT TIMER
;
;      INITIALIZES THE INTERRUPT TIMER TO
;      CAUSE AN INTERRUPT IN 1 SECOND

```


---- SUBROUTINES ----

```

030B' 32 6116      SIT: LD      (ISTP),A      ;ENSURE TIMER STOPPED
030E' 3E 09        LD      A,00001001B
0310' 32 6119      LD      (IMOD),A      ;T1 = EVENT COUNTER
0313' 21 FFFF      LD      HL,-1        ;850 MILLISECONDS
0316' 22 6112      LD      (IDIV),HL
0319' 32 6117      LD      (ISTR),A      ;START THE TIMER
031C' FB          EI                    ;ENABLE INTERRUPTS
031D' C9          RET

```

```

;      STC - SEND TERMINAL CHARACTER
;
;      SENDS A CHARACTER TO THE TERMINAL
;
;      ENTRY (A) - CHARACTER

```

```

031E' 32 E000      STC: LD      (SIOD),A      ;SEND CHARACTER
0321' F5          PUSH     AF
0322' 3A E001      STC1: LD      A,(SIOS)
0325' E6 01        AND      STDR
0327' CA 0322'     JP      Z,STC1        ;IF XMIT BUSY
032A' F1          POP      AF
032B' C9          RET

```

```

;      TEM - TRANSMIT ERROR MESSAGE
;
;      SENDS AN ERROR MESSAGE TO THE CONSOLE

```

```

032C' 21 038D'     TEM: LD      HL,IMSG
032F' 7E          TEM1: LD      A,(HL)      ;GET NEXT CHAR
0330' 23          INC      HL
0331' CD 031E'     CALL     STC            ;SEND TO TERMINAL
0334' FE 04        CP      EOT
0336' C2 032F'     JP      NZ,TEM1        ;IF NOT END OF TEXT
0339' C3 0087'     JP      MCL            ; ELSE BACK TO MAIN

```

```

;      VDB - VALIDATE DATA BUFFER
;
;      PERFORMS A VALIDITY CHECK OF THE RECEIVE INPUT
;      DATA BUFFER RECEIVED FROM "MIRDAT".

```

```

033C' 11 0020"     VDB: LD      DE,RBUF      ;CHECK BIT BUFFER POINTER
033F' 21 0018"     LD      HL,RBUF+BSIZ     ;CHECK BIT POINTER
0342' 06 08        LD      B,BSIZ/2
0344' 97          SUB      A
0345' ED 6F        VDB1: RLD

```

```

0347' 12          LD      (DE),A          ;STORE UPPER BITS
0348' 13          INC      DE
0349' ED 6F        RLD
034B' 12          LD      (DE),A          ;STORE LOWER BITS
034C' 13          INC      DE
034D' 23          INC      HL
034E' 10 F5        DJNZ    VDB1          ;UNTIL DONE

0350' DD 21 0008"  LD      IX,RBUF        ;BUFFER POINTERS
0354' 21 0020"    LD      HL,RBUF
0357' 11 0000      LD      DE,0          ;VALIDITY FLAG
035A' 06 10        LD      B,B5IZ        ;LOOP COUNTER

035C' DD 4E 00      VDB2: LD      C,(IX)      ;GET NEXT DATA BYTE
035F' CD 0258'     CALL    GHC            ;GENERATE HAMMING CODE
0362' 7E          LD      A,(HL)        ;GET CHECK BITS
0363' A9          XOR      C
0364' CA 037F'     JP      Z,VDB3        ;IF GOOD CHECK

0367' CD 024B'     CALL    GCB            ;GET CORRECTION BIT
036A' CA 037F'     JP      Z,VDB3        ;IF CHECK BIT WAS BAD

036D' DD 7E 00      LD      A,(IX)
0370' A9          XOR      C            ;CORRECT BIT
0371' DD 77 00      LD      (IX),A
0374' 4F          LD      C,A
0375' CD 0258'     CALL    GHC
0378' 7E          LD      A,(HL)
0379' A9          XOR      C
037A' CA 037F'     JP      Z,VDB3        ;IF NOW GOOD

037D' CB C3        SET      0,E

037F' EB          VDB3: EX      DE,HL
0380' 29          ADD     HL,HL          ;SHIFT VALIDITY FLAG
0381' EB          EX      DE,HL
0382' DD 23        INC      IX          ;ADVANCE DATA POINTER
0384' 23          INC      HL          ; AND CHECK BIT POINTER
0385' 10 D5        DJNZ    VDB2        ; UNTIL DONE

0387' ED 53 003D"  LD      (VFLG),DE      ;SET VALIDITY FLAG
0388' C9          RET

038C' 00          NOP                  ;COVER UP L80 BUG

```

SUBTTL ---- MESSAGES/TABLES/BUFFERS/VARIABLES ----
 PAGE

```

;      MESSAGES

038D'  21 21 20 49      IMSC:  DB      ' ' INVALID COMMAND ' ',NL,EOT
0391'  4E 56 41 4C
0395'  49 44 20 43
0399'  4F 4D 4D 41
039D'  4E 44 20 21
03A1'  21 1F 04
03A4'  2A 20 2A 20      TMSG:  DB      '* * INTERRUPT * ',NL,EOT
03A8'  49 4E 54 45
03AC'  52 52 55 50
03B0'  54 20 2A 20
03B4'  2A 1F 04

;      TABLES

03B7'  2710 03E8      DPVT:  DW      10000,1000,100,10,0
03BB'  0064 000A
03BF'  0000
03C1'  00 00 00      STEL:  DB      0,0,0
03C4'  01              DB      1              ;0
03C5'  00              DB      0
03C6'  02 04 08      DB      2,4,8              ;1,2,3
03C9'  00              DB      0
03CA'  10 20 40 80      DB      16,32,64,128      ;2,3,4,5
03CE'  00 00 00 00      DB      0,0,0,0

;      BUFFERS
;      (( COMMAND BUFFER MUST BE FIRST ITEM ))

03D2      DSEG

0000"      CBUF:  DS      CSIZ+2      ;COMMAND INPUT BUFFER
0008"      RBUF:  DS      BSIZ+HSIZ   ;RECEIVE BUFFER
0020"      BBUF:  DS      BSIZ        ;CHECK BIT BUFFER
0030"      RSLT:  DS      5           ;QUOTIENT BUFFER

;      VARIABLES

0035"  0000      BFTR:  DW      0      ;INPUT BUFFER POINTER
0037"  0000      CCNT:  DW      0      ;TEST CYCLE TIME
0039"  0000      CTIM:  DW      0      ;TEST CYCLE TIMER
003B"  00        TEMP:  DB      0      ;WORKSPACE
003C"  00        TFLG:  DB      0      ;TEST FLAG
003D"  0000      VFLG:  DW      0      ;VALID DATA FLAG
  
```

SUBTTL ---- SYMBOL REF TABLE ----
 END

Macros:

Symbols:

A104	ADDR	6100	APRT	0020"	BBUF
6109	BCLR	0035"	BPTR	0008	BS
610D	BSET	0010	BSIZ	0000"	CBUF
610A	CCLR	0037"	CCNT	0044'	CIN
000D	CR	610E	CSET	0006	CSIZ
0039"	CTIM	011F'	CTM	0181'	DCN
018B'	DCN1	0193'	DDV	019E'	DDV1
01A4'	DDV2	01B2'	DDV3	01BA'	DDV4
01CA'	DDV5	01D3'	DDV6	01DC'	DDV7
01F0'	DDV8	03B7'	DDVT	01FC'	ECS
0201'	ECS1	021F'	ECS2	0230'	ECS3
0004	EQT	001B	ESC	024B'	GCB
0258'	GHC	0263'	GHC1	026B'	GHC2
0273'	GHC3	027B'	GHC4	0008	HSIZ
6112	IDIV	6119	IMOD	038D'	IMSG
0038'	INT	6116	ISTP	6117	ISTR
000A	LF	0087'	MCL	0094'	MCL1
00AC'	MCL2	00CB'	MCL3	00E6'	MCL4
0104'	MCL5	027F'	MSD	0280'	MSD1
0282'	MSD2	0297'	MSD3	001F	NL
0008"	RBUF	0299'	RDB	02A6'	RDB1
02B5'	RDB2	0002	RECV	0126'	ROD
013C'	ROD1	0030"	RSLT	0000'	RST
02D4'	SBT	02E0'	SBT1	02FD'	SBT2
0150'	SCT	0155'	SCT1	0174'	SCT2
0002	SIDR	0040	SIIR	E000	SIOD
E001	SIOS	030B'	SIT	0080	SIXR
0001	SOM	607E	STAK	03C1'	STBL
031E'	STC	0322'	STC1	0001	STDR
017B'	STM	0003	STX	6115	TBRG
6114	TBR5	6110	TDIV	032C'	TEM
032F'	TEM1	003B"	TEMP	003C"	TFLG
6118	TMOD	03A4'	TMSG	033C'	VDB
0345'	VDB1	035C'	VDB2	037F'	VDB3
003D"	VFLG	0001	XMIT		

No Fatal error(s)

Standard Bibliographic Page

1 Report No NASA CR-177953		2 Government Accession No		3 Recipient's Catalog No	
4 Title and Subtitle Miniature Infra-Red Data Acquisition And Telemetry System				5. Report Date September 1985	
				6 Performing Organization Code	
7 Author(s) J. H. Stokes and S. M. Ward				8 Performing Organization Report No 17944	
				10. Work Unit No	
9 Performing Organization Name and Address Energy Optics, Inc. P.O. Box 15052 Las Cruces, NM 88004				11. Contract or Grant No NAS1 - 17944	
				13. Type of Report and Period Covered Contractor Report	
12 Sponsoring Agency Name and Address National Aeronautics And Space Administration Washington, DC 20546				14. Sponsoring Agency Code 324-01-00	
15 Supplementary Notes Langley Technical Monitor: Jag J. Singh Phase I Final Report					
16 Abstract <p>The Miniature Infrared Data Acquisition and Telemetry (MIRDAT) Phase I Study was performed to determine the technical and commercial feasibility of producing a miniaturized electro-optical telemetry system. This system acquires and transmits experimental data from aircraft scale models for real-time monitoring in wind tunnels.</p> <p>During the Phase I Study, miniature prototype MIRDAT telemetry devices were constructed, successfully tested in the laboratory and delivered to the user for wind tunnel testing. A search was conducted for commercially available components and advanced hybrid techniques to further miniaturize the system during Phase II development. A design specification was generated from laboratory testing, user requirements and discussions with component manufacturers. Finally, a preliminary design of the proposed MIRDAT system was documented for Phase II development.</p>					
17 Key Words (Suggested by Authors(s)) Miniature Infrared Telemetry			18 Distribution Statement Unclassified - Unlimited Subject Category 35		
19 Security Classif (of this report) Unclassified		20 Security Classif (of this page) Unclassified		21. No of Pages 92	22 Price A05

For sale by the National Technical Information Service, Springfield, Virginia 22161

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